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ABSTRACT

A number of space science resource materials and activities are developed into a useful format for classroom presentation. The application of mathematical properties in making scientific discoveries is the major emphasis. Each section has a discussion centered on the men and history behind the discovery of physical laws and phenomena relevant to space flight and exploration. The discussion provides interest and stimulation for the suggested experiments and problems. This document provides a valuable supplement for use with secondary school topics such as ratios, logarithms, vectors, analytic geometry and trigonometry. (JP)

MATHEMATICS IN SPACE SCIENCE

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FROM HERE, WHERE?

A space mathematics supplement for secondary levels

FROM HERE, WHERE?
GETTING INTO SPACE
SPACE AND WEATHER
SPACE NAVIGATION
THE RIDDLE OF MATTER AND MOTION
THE MEASURE OF SPACE
THE SPACE ENVIRONMENT
GLOSSARY OF TERMS USED IN THE EXPLORATION OF SPACE

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FROM HERE, WHERE?

A source book in space oriented mathematics
for secondary levels.

Prepared from materials furnished by the National Aeronautics and Space Administration in cooperation with the United States Office of Education by a Committee on Space Science Oriented Mathematics

1965

ERRATA

The printers inadvertently reduced the navigation maps on pages 62 and 65. Therefore, the answers to problems 3, 4, and 12b shown on page 123 should be disregarded.

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INTRODUCTION
To Students and Their Teachers

Throughout history men have looked to the sky. From the motions of the stars and planets they have charted their travels, planted their crops, set the time of the days and of the seasons. Today we not only *look* into space—we *go* there.

Every one of us is a part of what is now called the Space Age. As we work and study together to make new discoveries, we share not only the benefits but also the responsibilities of this new and fascinating knowledge. We are finding that space exploration contributes much to making our world a better place in which to live. It has enabled us to predict and to chart the paths of storms, to produce more accurate maps, to improve our communications, and to discover the wonders of the universe which surround us. Every day orbiting satellites provide us with new knowledge, but all of this would be impossible without the use of mathematics.

Mathematics, one of man's oldest "tools," has become a very important discipline in this new age of discovery. Therefore, to assist students and teachers in relating mathematics to the space program, NASA/Goddard Space Flight Center and the United States Office of Education joined efforts and formed a Committee on Space Science Oriented Mathematics.

Dr. Michael J. Vaccaro, Assistant Director for Administration, Goddard Space Flight Center is chairman of the Committee, Dr. Patricia M. Spross, Specialist in Mathematics, U.S. Office of Education, is technical director and Mr. Alfred Rosenthal, Public Information Officer at the Goddard Center, publication director.

The first project developed by this group was "What's Up There," a space science mathematics source book for use in elementary grades. The second project of the committee has resulted in this publication designed to supplement the material usually studied in secondary school mathematics classes. The various chapters of this book were written by experienced teachers in a workshop held at the American University, Washington, D.C., conducted by Dr. Chalmers A. Gross.

Editorial consultants for this project were Mr. Harry L. Phillips and Dr. Lauren G. Woodby, specialists in Mathematics, U.S. Office of Education and Mr. Arthur J. McMahon, Consultant, Mathematics Education, Department of Education, Rhode Island.

The author of each chapter felt that he had something special to say to you about applications of mathematics in space science. It is the purpose of this book to arouse your interest and curiosity to search further and to make mathematics more meaningful as it relates to the new era it now serves. HAVE FUN!

PREFACE

Surrounded by a changing world, the teacher of today must relate new knowledge and new experiences to his students.

However, there is a gap between teacher needs and available textbook material. This problem is particularly acute in the areas affected by our efforts in the scientific exploration of space due to the exponential growth of scientific and technological information. Until the results of this research can be incorporated into textbooks for classroom use, supplemental material must provide a partial solution to meeting these needs.

This reference book was developed jointly by the U.S. Office of Education; the American University; and the NASA/Goddard Space Flight Center. Its authors are experienced classroom teachers who have translated the wealth of space science resource material developed by NASA into a format useful for classroom presentation.

We hope that this reference book will be an aid in bridging the information gap which faces our secondary students and teachers.

MICHAEL J. VACCARO
Chairman
Committee on Space Science
Oriented Mathematics

Chapter I

FROM HERE, WHERE

by
Robert A. Mousseau
Churchill Area High School
Pittsburgh, Pennsylvania

ABOUT THIS CHAPTER

What is science? The beginning and the end of it could be thought of as experience. Einstein stressed that: "knowledge about reality begins with experience and ends in it." The *what* of science is less important than *how* one obtains it, and the how is more meaningful to the person *who* does it.

As we learn the scientific method it takes many forms. Sometimes situations confront us with the need to think originally and we feel that we must reach out for conclusions. When we do this we add to the storehouse of knowledge and build on the experiences of the past. In doing it however, we will perhaps find that we *disagree* with the past. As we study the great men of science we will find that this has been true. They were the scholars who knew and understood the past, but saw it in a different way. Therefore we need to know where we are, where we have been, and to have some idea of where we are going.

Sometimes we explore a topic individually and alone, at other times working with others will help us. The topics in this chapter are presented in such a fashion that you will experience each by some form of activity using simple tools like the straight edge, compass, pencil, and protractor. You will be investigating the mathematics of ratio and proportion, exponents, logarithms, and vectors. Sample each and as you do, think what the great Galileo said many years ago: "You cannot teach a man anything, you can only help him to find it within himself. . . ."

Man is born with an insatiable curiosity concerning his natural environment. The restraints upon his satisfying this innate curiosity have been the shackles of superstition and myth, and the lack of proper tools, such as the microscope, telescope, bathysphere and booster to help him carry his investigations further and his probes deeper. In today's refined technology, man is rapidly developing the tools with which he can explore not only the earth but also the celestial environment around it.

The space program draws on many areas of science . . . physics, astronomy, and the earth sciences. A general spirit of inquiry into the nature of the earth and its relationship to space draws them all together. The catalyst of space science is mathematics.

Today we stand on the threshold of the Second Age of Discovery. The space-age "Columbus" and "Magellan" are not now known, but somewhere and sometime they will be sitting in school preparing for an adventure that far exceeds the greatest of dreams. It may distract them from their books!

There is reason for teachers and students to look for new answers to age old questions. This booklet suggests experiences which can help you to understand the mathematics of space and which can lead you to develop new ideas. There is something here for everyone. The experiences will show you how you can apply the mathematics you study to space exploration. Work hard and see what you can find out.

"Space has devoured ether and time; and it seems to be on the point of swallowing up the field and corpuscles, so that it alone remains as the vehicle of reality. . . ." Einstein.

CONCENTRICS, CYNICS, AND COPERNICUS

Discovery—A Never Ending Process

Space is the new frontier for research. The launching of the first man-made satellite plunged man headlong into this new laboratory. Today every American is challenged with the opportunity to participate in individual research. Those who do take advantage of the opportunity are rewarded with the thrills of discovery as experienced by such men as Archimedes, Ptolemy, Copernicus, Galileo, Kepler, and Goddard.

Discovery has many forms and often unexpectedly announces its arrival only when we feel defeated after long investigations and many observations. Research in space is an open door to the study of mathematics and science.

What experiences and observations do you need today for the age of tomorrow? We can gain insight into the problem by going back into history and visiting some of the men whose discoveries and observations of physical phenomena have helped mankind to a better understanding of this place we call space.

Concentric Circles Have No Alpha or Omega

Let us enter the "time capsule" and journey back into time. Set the controls for the second century somewhere in Alexandria, Egypt, for we are about to visit Claudius Ptolemaeus, better known as Ptolemy (toé-la-me). Here we see a man pouring over tables of data searching for answers to questions and problems about the planets and the stars. One of the craters on the moon has been named for this man.

He seems to be drawing a series of lines which have no beginning and no ending. Yes, Ptolemy is drawing circles, one within the other—a rather strange activity for a grown man!

Ptolemy has been called the greatest astronomer of antiquity because his scientific investigations improved and extended the theories of his predecessors. Yet even Ptolemy has been criticized by our astronomers of today. They claim that he was so possessed by blind faith that he would falsify his own observational results to make them agree with the data furnished at that time.

The scientific method used by Ptolemy was different from ours. He had no regular experimental research with acknowledged standards of judgment. Observational results were not considered documents to add to the storehouse of knowledge. There were few tools. New theories were clouded and condemned by fear and superstition . . . and Ptolemy's work was essentially theoretical.

Much of his work was concentrated on the planets and their strange motions in the sky. Of course, everyone living then "just knew" that all of the planets and stars revolved about the Earth. Eudoxus and Aristotle had shown this by using *concentric circles* and spheres. Eudoxus used twenty-seven *concentric spheres* while Aristotle required fifty-five. These concepts were believed back in 700 B.C.

Solar Systems

Let us take a little closer look at just what Ptolemy is drawing. It seems that he is trying to show pictorially how the planets move through the constellations. For the most part, they move counter clockwise, if one's observation point is Polaris, our North Star. This is known as their *direct motion;* for it is in this direction that the planets revolve about the sun, although Ptolemy did not realize this. At intervals, which are not the same for the different planets, they turn and seem to move backward as they are observed from our earth. They *retrograde* for a while before resuming the forward motion. They are said to be stationary at the turns.

The most enduring early plan for solving the problem of the planetary motions was developed by Ptolemy. It was a plan of *epicycles* and was labeled the Ptolemaic Solar System as illustrated in figure 1. Note the use of concentric circles.

The epicycles were formulated by him to account for what we call retrograde motion. The center of the "epicycle circle" was sometimes called the "fictitious planet" which was moving on a larger circle called the *deferent.* The planet itself was theoretically carried on the end of a "crank-arm" pivoting on the fictitious planet for its center. In the diagram no attention is paid to dimensions, the deferents being spaced at equal distances.

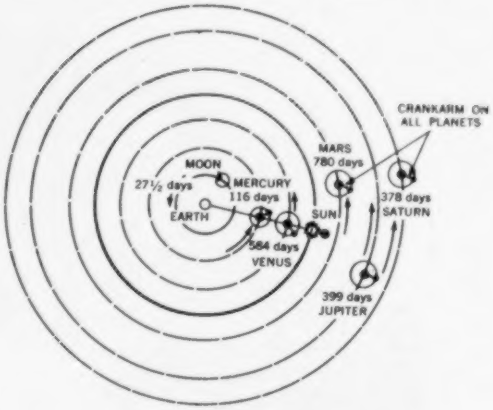

Figure 1. Ptolemaic Solar System

This scheme was the result of a very carefully thought out plan to account for the observed motions. Remember, such observations were made without the aid of a telescope.[1]

Let us now go back to another time in our capsule and make another visit. This time we shall look in on a famous astronomer for whom one of the most conspicuous craters on the moon was named. He is Tycho Brahe (Tie-co Bra-he), a Danish astronomer whose passion for astronomy was shown in his secret nightly studies and observations. Tycho was convinced of the truth of astrological doctrines, and he often computed horoscopes. We must not criticize him too severely for this because even today, in our modern world of science, there are people who still believe in fortune-telling.

The time is around 1590 A.D. and we see Tycho at one of his instruments making observations of some celestial object from the observatory which he built and equipped with the finest astronomical instruments in existence. One should remember that Tycho's instruments

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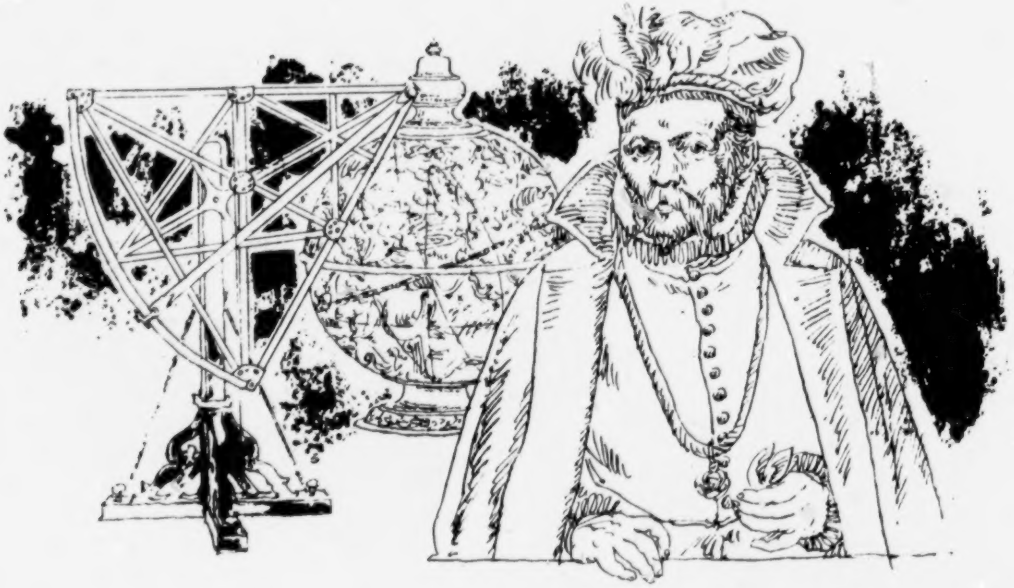
[1] Ralph A. Wright, *Astronomy Charted* (4 Mason Street, Worcester, Massachusetts, Copywright 1948), p. 1.



did not include the telescope which was still to be invented. Yet his work as an observer was meticulous in the extreme. He plotted planet positions night after night, almost hour after hour. His accuracy was phenomenal and he developed a system of averaging the results of his observations in order to eliminate, as nearly as possible, any human errors.

It is said that he held his science in such respect that he never entered the observatory unless he was dressed in the finest clothes he owned. His overall purpose was the correction of the astronomical theories which existed at that time. No efforts comparable to his had been made since the days of Ptolemy.

Tycho suggested several modifications to the Ptolemaic system. He held that the Earth was stationary in space, and also used concentric circles to picture the solar system. Figure 2 illustrates Tycho's concept of the solar system.

Tycho Brahe made a great advance in the astronomical thought of his day. He still gave the Earth the honor of being the center of the solar system, but according to his theory, the moon and sun revolved about the Earth while the other planets revolved about the sun. While the plan was not wholly sound, it did take a step in the right direction. One must remember the dangers involved in disagreeing with the then-accepted theory of the day. Disagreement with the existing theories of Tycho's day might have meant being burned at the stake. Credit should go to Tycho Brahe for reasoning out one more advanced step in astronomical knowledge.[2] One should also remember King Frederic of Denmark who made it

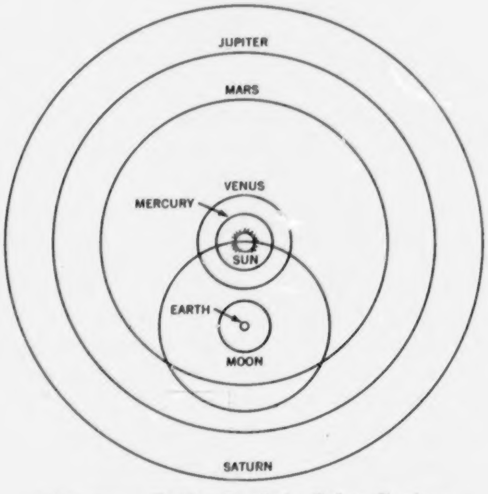


Figure 2. Tycho Brahe's Solar System

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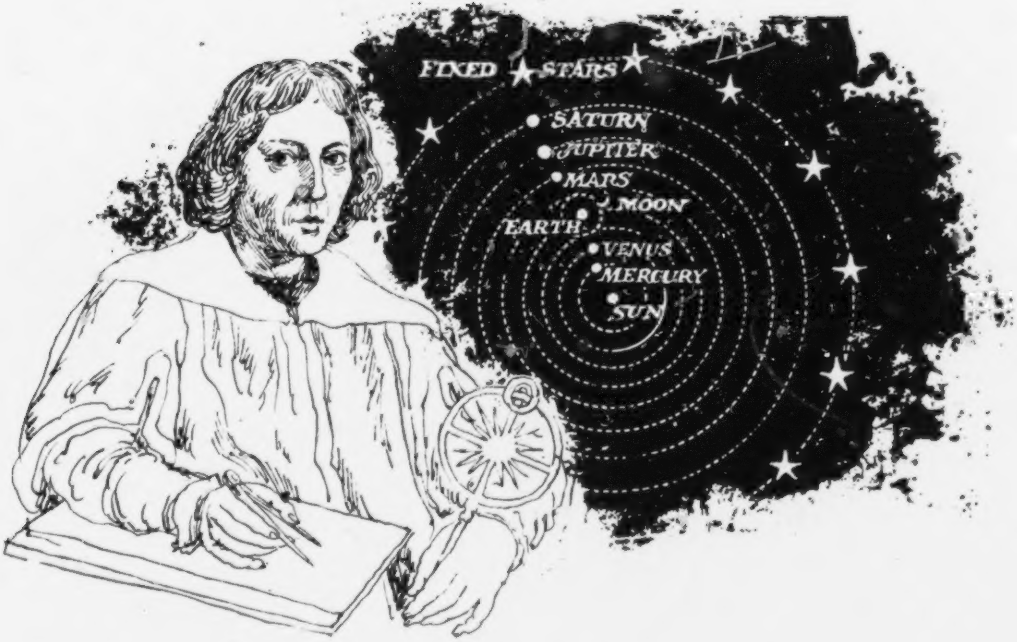
[2] Ralph A. Wright, *Astronomy Charted* (4 Mason Street, Worcester, Massachusetts, Copywright 1948), p. 2.



possible for Tycho to build his observatory on the small island of Hven, near Copenhagen in the Öre Sound.

Now it is time for us to leave Tycho's observatory and move on to another country in Europe. Our "time capsule" now takes us to the city of Thorn in Prussian Poland and the year is 1530. A man named Nicolaus Copernicus is writting a treatise in which he expresses dissatisfaction with the Ptolemaic system.

The doctrine of Copernicus meant a complete upheaval in man's concept of the world which, as the new truth spread, was to dominate modern thinking ever after. What was called the deferent of Mars or Jupiter was now called its "real orbit." He used new observations (mostly made by himself) to derive the orbits for the present time with more accurate *periods* of revolution, and he computed new tables. Thus he produced a new manual of astronomy suited to replace Ptolemy in every respect. Figure 3 illustrates the solar system as pictured by Copernicus.

Nicolaus Copernicus was another astronomer who placed a milestone in man's progress through the ages. The diagram above will show some errors, yet an advance is clearly seen with the sun finally established as the center of the solar system. It is adapted in part from a theory of the ancient Pythagoreans. Later carried forward by Greek and Latin writers. Copernicus, pondering on these

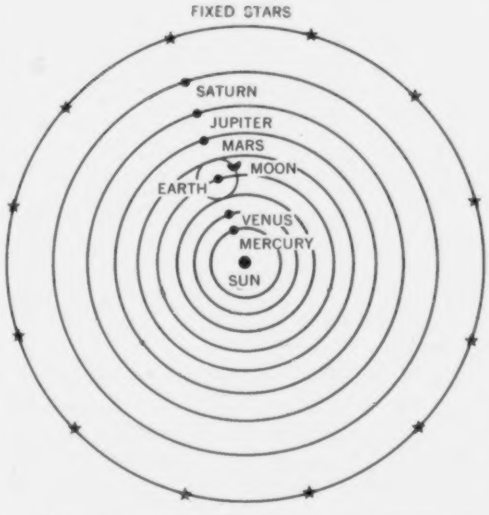
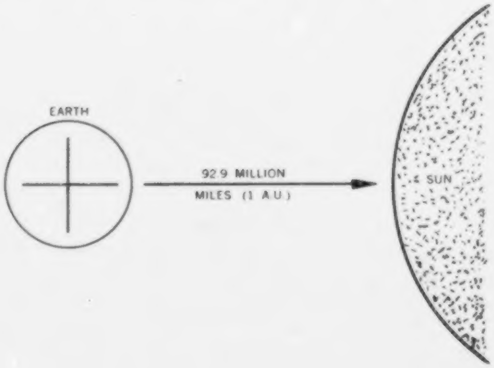


Figure 3. The solar system of Copernicus

theories, formulated his "True Heliocentric System." He retained some of Ptolemy's epicycles and eccentricities that were finally eliminated by Kepler, but the foundation of a central sun was laid for us to build upon. Fortunately Copernicus' work was not published as "De Revolutionibus Orbium Celestium" until the year after his death. Bruno, another early theoretician, was burned at the stake in the year 1600 for affirming his loyalty to the new theory. Today astronomers continue to advance on the stepping stones he placed.[3]

The fuel gauge on our time capsule indicates we must return to our own era and refuel. This will provide us with a rest and a chance to ponder over the strange visits we have just made.



SOLAR SYSTEM STATISTICS

Ratio and Proportion

With a knowledge of ratio and proportion, you can duplicate Copernicus' illustration of our solar system. All that you need is a reference book giving the *mean* distances of the planets from the sun, a compass, and a metric ruler. You can then convert, or change, these distances into what is more commonly called astronomical units (A.U.). You will need to know the following:

mean distance = average distance

$$= \frac{\text{perihelion} + \text{aphelion}}{2}$$

Earth's mean distance from the sun is about 92.9 million miles; therefore, 1 astronomical unit = 92.9 million miles = 1 A.U. (We use the Earth's mean distance from the Sun as 1 A.U.)

A ratio is the quotient of two numbers, as $\frac{2}{3}$ or a/b.

A proportion is a sentence equating two ratios, as, $\frac{2}{3} = \frac{4}{6}$ or a/b = c/d.

Astronomical Units

Since one astronomical unit equals the Earth's mean distance from the sun, then the planet Saturn's mean distance from the sun could be represented in astronomical units as follows:

$$\text{Since } \frac{\text{mean distance of Saturn in miles}}{\text{mean distance of Earth in miles}} = \frac{\text{Saturn's distance in A.U.}}{\text{Earth's distance in A.U.}}$$

$$\text{and } \frac{886{,}200{,}000 \text{ miles}}{92{,}900{,}000 \text{ miles}} = \frac{\text{Saturn's distance in A.U.}}{1 \text{ A.U.}}$$

$$\text{hence } 9.5 \text{ A.U.} = \text{Saturn's distance in A.U.}$$

Surely there must be an easier way to do this! A man named John Ehlert Bode did it. Let us examine some special numbers in a series. Start with 0, and then 3, and double every number thereafter beginning with three, 0, 3, 6, 12, 24, . . . and so on.

Next, add 4 to each member of the given set. This gives us

$\{0 + 4, 3 + 4, 6 + 4, 12 + 4, 24 + 4, \ldots\}$

Now divide each new element of the set by 10. Now we are talking about the values in a set:

$$\left\{\frac{0+4}{10}, \frac{3+4}{10}, \frac{6+4}{10}, \frac{12+4}{10}, \frac{24+4}{10}, \ldots\right\}$$

Take a close look at each of the resulting elements of this final set. Do you see anything strange? Can you relate them to anything we have discussed so far?

No one has yet come up with a satisfactory explanation of how a man named

---

[3] Ralph A. Wright, *Astronomy Charted* (4 Mason Street, Worcester, Massachusetts, Copywright 1948).

John Ehlert Bode derived these numbers. Textbooks only mention Bode's Law for its use in approximating mean distances of the planets in astronomical units.

Yes, the resulting elements of our set represent, approximately, the mean distances of the planets from the sun in astronomical units. See table 1 below.

Table 1.–Bode's law

Planets	Bode's Number	Add 4	(Experimental) Divide by 10	Distances in A.U. (True)
Mercury	0	4	0.4	0.39
Venus	3	7	0.7	0.72
Earth	6	10	1.0	1.00
Mars	12	16	1.6	1.52
Asteroids	24	28	2.8	2.65
Jupiter	48	52	5.2	5.20
Saturn	96	100	10.0	9.54
Uranus	192	196	19.6	19.19
Neptune	384	388	38.8	30.07
Pluto	786	772	77.2	39.52

A close agreement with actual distance is shown in table 1 in the case of the minor planets. Legend states that Giuseppi Piazzi discovered Ceres, the first asteroid, as a result of applying Bode's Law. Actually, he accidentally discovered the asteroid Ceres on the first night of the nineteenth century.

The Experimental Method

One should always be able to make comparisons when data are used at any time. For example, we should be able to calculate how much error there is in Bode's Law, if any.

A ratio is used to calculate what is called the per cent of error.

Note: Per cent of error

$$= \frac{|\text{Experimental value} - \text{True value}|}{\text{True Value}},$$

expressed as per cent.

The vertical lines in the numerator represent a symbol meaning that only the positive or plus value can be used. This means that if the true value is greater than the experimental value and we would get a negative number in the numerator, it would always be treated as a positive number. This is usually called the "absolute value" of a number.

For example, the percent of error using Uranus would be as follows:

$$\text{Per cent error} = \frac{|\text{Experimental} - \text{True}|}{\text{True}}$$

expressed as per cent

$$= \frac{|19.60 - 19.19|}{19.19}$$

$$= \frac{0.41}{19.19}$$

$$= 2.14\% \text{ error}$$

Table 2.–Our solar system

Name		Symbol	Mean Distance from Sun		Period of Revolution		Eccentricity of Orbit	Miles Mean Diameter in	Mass $\oplus=1$	Density $H_20=1$	Period of Rotation	Stellar Magnitude at Greatest Brilliance
			Astron. Units	Million Miles	Sidereal	Syndic						
	Mercury											
	Venus											
	Earth											
	Mars											
	Jupiter											
	Saturn											
	Uranus											
	Neptune											
	Pluto											
	Sun											
	Moon											

Robert H. Baker, An Introduction to Astronomy (New York: D. Van Nostrand Company, Inc., 1962).

Questions.

1. Were there any entries which were not obtainable or else in doubt as to accuracy? If so, which ones and give your own reason as to why?
2. Are all of the numbers positive? Can you explain your answer at this time?

Note:–Answers for this table are supplied in the answer list at the back. (The inclusion of the table with answers is at your discretion.)

A student should now be able to construct an accurate picture of the solar system as seen by Copernicus using the data from table 1. A suggestion would be to use a scale where 1 A.U. = 1 cm.

Make the sketch and then see if you can answer the following questions.

1. What are concentric circles?
2. Can you give some examples of concentric circles?
3. Do you know the meaning of geocentric and helio-centric?
4. Why are there only seven objects listed in the solar system as pictured by Copernicus?
5. Do you know the Greek alphabet and its use in astronomy? (See any good dictionary for this.)

*Individual Research**

Build a table of numbers (table 2) representing the solar system as we know it today. Use any library references such as encyclopedias or astronomy texts. The table should be neat and kept in a notebook for further reference. The column title must be defined before any entry is allowed. Table 2 is one example of some important data which are used in space research.

* To the teacher—This table could be placed on one spare chalkboard in the classroom or else on heavy cardboard poster type material. The students could work in assigned groups or teams to fill in the needed information. A certain time allotment previously agreed upon by the students and the teacher for completion usually acts as a high motivation factor

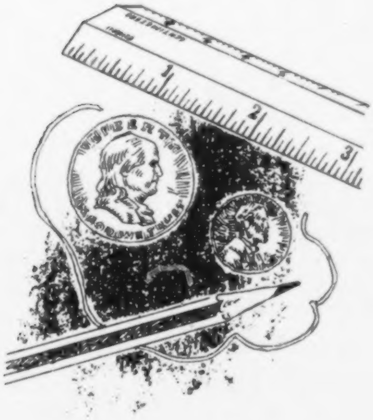
in the procurement of data. Stress the need of using many sources to check the accuracy of the data acquired. Averages could be used if discrepancies occur.

ORBITS OF THE EARTH AND MARS

Laboratory experiment:

Object: To determine experimentally the distance travelled by the planets Earth and Mars as they revolve about the sun.

Apparatus:
1 Benjamin Franklin half-dollar
1 Abraham Lincoln penny
1 piece of twine at least 10 cm. long
1 Metric-English ruler
1 pencil



Procedure: Measure the radii of the penny and half-dollar, and allow each one to represent respectively the mean distances of the Earth and Mars from the sun in astronomical units.

Place the fifty-cent piece on the paper and draw its circumference. Now place the penny concentrically within the circumference of the half dollar and draw this smaller circumference.

Now use the string and ruler to determine the actual circumferences of the two coins by wrapping the string around each and measuring the length of string used each time. Take your measurements in centimeters and call one centimeter one astronomical unit. Compare your observations and measurements with those you may have found in the references you used for Table 2.

Calculate the circumferences of these "orbits" using $C = \pi d$ where C = circumference, $\pi = 3.14$, and d = diameter in centimeters.

Secure the best information you can find which gives the distance of the true orbit in astronomical units. Compare your experimental value with this true values and determine a percent of error. Make three trials and then obtain an average for discussion purposes.

List your data in a table similar to the ones provided below.

Table 3.–Earth's orbit

Trials	Diameter	Experimental Circumference	Calculated (true) Circumference (from a reference book)	Percent Error
1				
2				
3				
Σx				
x				

Table 4.–Mars' orbit

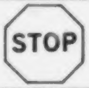
Trials	Diameter	Experimental Circumference	Calculated (true) Circumference (from a reference book)	Percent Error
1				
2				
3				
Σx				
$\bar{x}$				

Questions 1. What conclusions can you make concerning your data?
2. Was the percent of error high? Why?
3. How does your data compare with that of table 2?

SYMBOLIC SHORTHAND

An Application of Set Theory

Have you ever tried to abbreviate names and places in order to write faster? Mathematicians do this every day; in fact, almost everyone uses symbols of one kind or another. A *symbol* is a mark, a sign, or a word that represents an object or an idea. The following are all symbols:

?, +, ¢, 4, and 

Can you think of any others? Here are some of the more common symbols of arithmetic.

0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
+ - x ÷

Figure 4. Common symbols of arithmetic

Many schools today are using symbols which are somewhat new in introducing sets. A *set* is described as any collection of distinct objects. An elementary concept dealing with sets is one of membership in a particular group. It should be emphasized that a set is determined by its members or elements. For example, the set of stars is the set whose elements are stars, and both planets and common satellites are excluded from this group or set.

One should remember that two sets are equal if and only if they have the same elements. The symbol for a set is a brace { } and the set of stars can be represented as {stars}. Considering the number of stars in the universe, one could describe {stars} as an infinite set since there *seems* to be an infinite number of stars in the universe.

When I Heard The Learn'd Astronomer

When I heard the learned astronomer,
When the proofs, the figures, were
ranged in columns before me,
When I was shown the charts and
diagrams, to add, divide, and
measure them,
When I sitting heard the astronomer
where he lectured with much
applause in the lecture-room,
How soon unaccountable I became tired
and sick,
Till rising and gliding out I wander'd
off by myself,
In the mystical night-air, and from
time to time,
Look'd up in perfect silence at the stars.
Walt Whitman

When on a moonless night, one observes the clear field of stars, a too common first impression is that there are "millions of them." A useful exercise might be to determine their number by direct count, a task not so difficult as it may sound.[4]

Laboratory experiment:

Title: A Visible Star Count.

Objective: To determine the number of stars visible on a given night.

Apparatus: 1 piece of white pine 1″ x 3″ x 6″
3 nails
1 protractor
1 ruler
1 hammer
1 clear cloudless night

Procedure: Obviously the dome on which the stars appear to be is hemispherical. It rises from the horizontal circle or plane known as the horizon to a point directly above the head of the observer. This point is called the zenith. In order to have a useable horizon it is necessary to be in open country with no intervening obstructions.

Next it is advisable to select a 30° arc on the horizon circle. Perhaps the best way to do this is to have three nails so driven into a board that by sighting from one (A) of them to, in turn, the second (B), then the third (C), the two lines of sight will enclose a 30° angle. (See figure 5).

Next arcs must be imagined drawn vertically from each horizon circle point determined by the sides of the 30° angle. Each of these vertical arcs must be produced until they meet at the zenith, directly overhead.

This construction (visual) has *delineated* a spherical triangle with one 30° side on the horizon circle, and two 90° sides intersecting at the zenith. This spherical triangle then contains one-twelfth of the area of the visible hemisphere. Without an inordinate amount of trouble the stars in this triangle can be counted. Except on very clear nights, there will be only about two hundred of them. This indicates that the entire number of stars visible at one time is about 2,500 and this is generally about right.

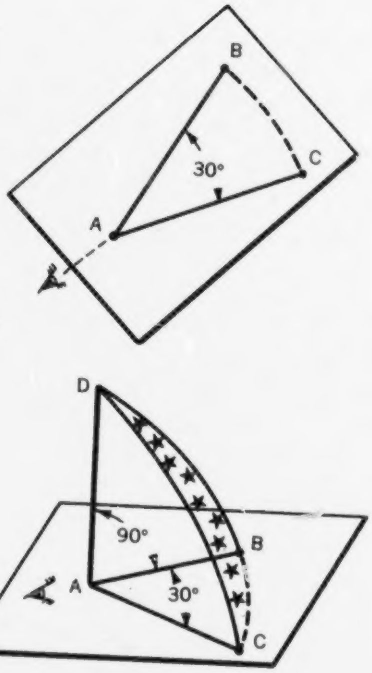


Figure 5. Spherical triangle DBC

However, people with exceptionally keen eyesight on exceptionally good nights for viewing may be able to see as many as 250 in such a spherical triangle, raising the maximum number of stars visible at one time by the unaided eye to approximately 3,000.

To the teacher: Have each member of the class make three trials and average their individual results. Then calculate a final average for the class and obtain a percent of error using three thousand as the accepted or true value. Have students observe stars in a triangle outside of the Milky Way. A triangle raised a little from the horizon may eliminate counting stars in the surface or horizon haze.

---

[4] Courtesy of Mr. Carl Heilman, Pennsylvania State Supervisor of Mathematics.

Table 5.–Data for a visible star count

Trials	Experimental	Accepted	Percent of Error
1			
2			
3			
Average ($\bar{x}$)			

Conclusion:

The student should write a conclusion to the laboratory experiment report and in it tell whether or not he succeeded in achieving the objective of the experiment. Reasons for error should be listed regardless of the size of the error. Suggestions can be included here as to how to improve on accuracy in this experiment.

One might now say that the number of visible stars is a subset of the set of stars. In other words,

$$\{\text{visible stars}\} \subset \{\text{stars}\}.$$

Have you learned the notation used in connection with sets? Here are some of the symbols used.

$$\{\}\quad \cup\quad \subset\quad \in\quad \emptyset\quad \cap$$

Figure 6. Symbols

A good student should know the meaning of each and be able to use them all. See a mathematics text for the meanings.

Alphabets

Mathematicians today need many symbols to carry on their work most efficiently. One would think the twenty-six letters in our alphabet would satisfy the need, but this is not true. The Greek alphabet is also used. The beginning letters correspond with ours:

Table 6.–Greek-English letter equivalents

α—alpha	a	ι—iota	i	ρ—rho	r, rh
β—beta	b	κ—kappa	k	σ—sigma	s
γ—gamma	g	λ—lambda	l	τ—tau	t
δ—delta	d	μ—mu	m	υ—upsilon	y, u
ε—epsilon	e	ν—nu	n	φ—phi	ph
ζ—zeta	z	ξ—xi	x	χ—chi	ch
η—eta	ē	ο—omicron	o	ψ—psi	ps
θ—theta	th	π—pi	p	ω—omega	ō

Look up the word alphabet in any good dictionary and then make a table of the Greek alphabet and compare or contrast it with ours. How many letters are there in the Greek alphabet? (You will find that the number varies. The alphabet changed over the centuries).

Table 7.–Greek alphabet

α—alpha
β—beta
γ—gamma
δ—delta
ε—epsilon
ζ—zeta
η—eta
θ—theta

ι—iota
κ—kappa
λ—lambda
μ—mu
ν—nu
ξ—xi
ο—omicron
π—pi

ρ—rho
σ—sigma
τ—tau
υ—upsilon
φ—phi
χ—chi
ψ—psi
ω—omega

Symbols and Stars

Astronomers today identify many stars using letters from the Greek alphabet. The plan of designating the brighter stars by letters was introduced by Bayer, a Bavarian attorney, in 1603. In a general way, the stars of each constellation are denoted by small letters of the Greek alphabet either in order of their brightness or according to location, and the Roman alphabet is drawn upon for further letters. An example is illustrated in Figure 7 and Figure 8.

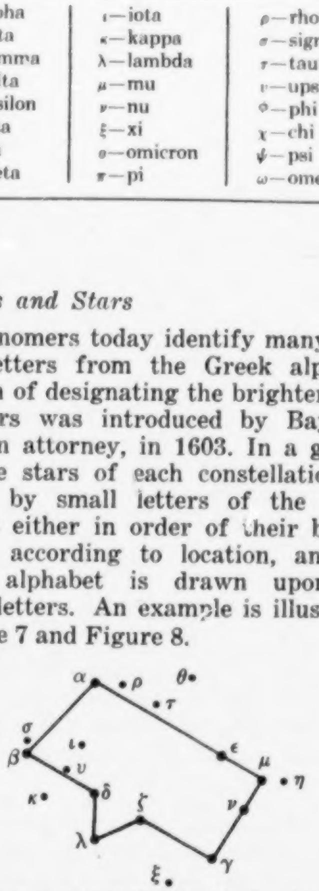


Figure 7. Constellation of Gemini

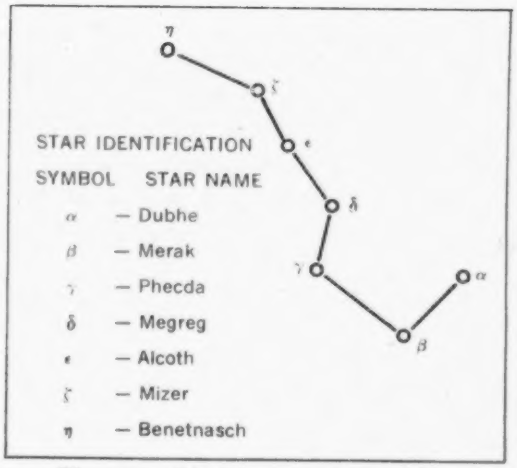


Figure 8. Big Dipper in Ursa Major

Figure 8 pictures the constellation Ursa Major more commonly known as the "Big Dipper" of the sky. Here the stars are lettered in order of position. On a clear night you should always be able to see this constellation if you live in the northern hemisphere since the Big Dipper is one of the circumpolar constellations.

Here is another list of symbols which are becoming more prominent in our space age. Astronomers use these to identify the following:

Table 8.—Signs and symbols

THE PLANETS		CONSTELLATIONS OF THE ZODIAC			
Mercury	☿	Spring Signs	♈	Aries	The Ram
Venus	♀		♉	Taurus	The Bull
			♊	Gemini	The Twins
Earth	⊕	Summer Signs	♋	Cancer	The Crab
Mars	♂		♌	Leo	The Lion
			♍	Virgo	The Virgin
Jupiter	♃	Autumn Signs	♎	Libra	The Scales
Saturn	♄		♏	Scorpius	The Scorpion
Uranus	♅		♐	Sagittarius	The Archer
Neptune	♆	Winter Signs	♑	Capricornus	The He Goat
Pluto	♇		♒	Aquarius	The Water Bearer
			♓	Pisces	The Fishes

OUR SUN is usually represented by the symbol ⊙.

Exponents and Logarithms

There are many interesting ideas about astronomy in the sections which follow. You may find some mathematics with which you are unfamiliar. Do not let that stop you. Refer to a good algebra text and see what you can do.

Work carefully. You may be surprised at how much you can accomplish.

Symbols are used to represent many different *parameters*. Sometimes numbers are used which have a special meaning. Parameters can be described as letters, variables, or constants which denote quantities or numbers.

Such is the case with numbers which represent exponents. For example, the small number 2 as written in 10^2 means that the number 10 (base 10) is to be used as a factor two times. In other words,

$$10^2 = 10 \times 10 = 100$$

(These are our common base-ten system numbers.)

By the same manner
(by definition)

$10^0 = 1$
$10^1 = 10$
$10^2 = 100$
$10^3 = 1{,}000$
$10^4 = 10{,}000$
$10^5 = 100{,}000$
$10^6 = 1{,}000{,}000$
$10^7 = 10{,}000{,}000$

It is now possible to see that a number between 10 and 100 could be represented by $10^{1.10}$ or $10^{1.30}$ or $10^{1.50}$.

The above numbers are read as 10 to the 1.1 power, 10 to the 1.3 power, and 10 to the 1.5 power respectively.

Some specific examples would be:

Table 9.–Exponents and decimals

$10^{0.954} = 9$
$10^{1.415} = 26$
$10^{1.477} = 30$
$10^{1.556} = 36$
$10^{1.602} = 40$
$10^{1.785} = 61$
$10^{2.00} = 100$
$10^{2.301} = 200$

Notice the exponents of the base 10 get larger as numbers increase from 9 to 200.

Let us change the name of the exponents in Table 9 above. Instead of calling 1.556 and 1.602 exponents, let us call them logarithms. From now on we shall refer to the exponents above as logarithms.

Instead of saying 10 to the 1.556 power is equal to 36 or $10^{1.556} = 36$, we shall now read it as the logarithm of 36 to the base 10 is 1.556. Shorthand notation is as follows: $\log_{10}36 = 1.556$.

Now you should try using this new abbreviation or symbol for a power of 10 or an exponent of 10.

Fill in any blanks which are missing.

Table 10.–Logarithms

LOGARITHM NUMBER

$\log_{10}9 = 0.954$
$\log_{10}26 = 1.415$
$\log_{10}30 = 1.477$
$\log_{10}36 = 1.556$
$\log_{10}40 = 1.602$
$\log_{10}61 = 1.785$
$\log_{10}100 =$
$\log_{10}200 =$

Table 10 represents a list of critical numbers and their logarithms.

The list is said to be critical since it is to be used in the next topic dealing with the brightness or magnitude of a star and some of the instruments used to detect their presence.

When observations of stars are made, very obvious differences in color and brightness of stars are seen. If optical aids are used to supplement direct vision, such differences in color and brightness become noticeable.

Furthermore, the use of even low power field glasses, opera glasses, or small telescopes will serve to demonstrate how many more stars can be made visible in a given area of the sky by such aids. Also, it will be noticed that such optical aids do not increase the size of the star's image; they merely intensify its brightness. This last comment does not, of course refer to the planets, which must not be confused with the stars.

Since differences in sizes of stars are not readily apparent, differences in brightness serve much better for purposes of classification. The unit of brightness of stars is known as the *stellar magnitude.* Stellar magnitude is defined by saying that if two stars so differ in apparent luminosity that one appears 100 times as bright as the other, then they will differ by five magnitudes. The magnitude difference is divided into equal steps, such that two stars differing by one magnitude will differ by a factor of 2.512 which is the fifth root of 100.

The ratio of brightness between two stars differing by exactly one magnitude is the number whose logarithm is 0.4, which is about 2.512. In other words $10^{0.4} = 2.512$.

Table 11 illustrates the contrast between magnitude and brightness.

Note: $(2.512)^1 = 2.512$
$(2.512)^2 = 6.31$
$(2.512)^3 = 15.85$
$(2.512)^4 = 39.8$
$(2.512)^5 = 100.0$

Perhaps by noting the exponents of 2.512, the student can see why the concept

Table 11.–Magnitudes and brightness

Magnitude	Ratio of Brightness	
1.0 magnitude	2.512	Decreasing Brightness ↓
2.0 magnitude	6.31	
3.0 magnitude	15.85	
4.0 magnitude	39.8	
5.0 magnitude	100.0	

of magnitude is a function of logarithms.

The two stars in the Big Dipper's bowl next to the handle are of the third magnitude. The other five stars in the constellation are of the second magnitude.

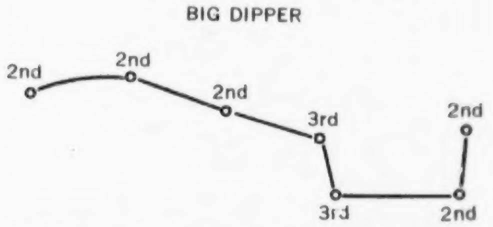


Figure 9. Star magnitudes in the Big Dipper

Table 12.–Star magnitudes

Stars	Magnitude
α	2nd
β	2nd
γ	3rd
δ	3rd
ε	2nd
ζ	2nd
η	2nd

Second magnitude stars are approximately 2½ times brighter than the third magnitude stars. The reader should try to associate these stars with others to approximate star magnitudes.

By now it should be obvious why the experiment on a visible star count produced such a relatively low number compared to the actual number of stars present in the universe. The average human eye can only detect stars up to the sixth magnitude in brightness. Beyond the sixth magnitude, an optical instrument is required for any observation of dimmer objects.

However, even the optical instruments of today's modern science have their limitations. The limiting magnitude of any optical telescope can be calculated using this mathematical relationship.

$\text{L.M.} = 8.8 + 5 \log_{10} D$

where L.M. = limiting magnitude of a telescope and $\log_{10} D$ = the logarithm of the measure of the diameter of the lens in the telescope.

Hence the limiting magnitude of a homemade telescope can be calculated before it is built and the person building the telescope can anticipate the magnitudes of the faintest stars he will have the good fortune of viewing.

Here again is further indication of the importance of a knowledge of mathematics in this space oriented age we are entering.

Sample problem:—What is the limiting magnitude of a home made 6-inch reflecting telescope? ($\log_{10}6 = 0.778$)

Solution:

$$\begin{aligned}\text{L.M.} &= 8.8 + 5 \log_{10} D\\ &= 8.8 + 5\,(0.778)\\ &= 8.8 + 3.890\\ &= 12.690\end{aligned}$$

Answer:—This homemade 6-inch telescope will enable its maker to view stars of the *12.69 magnitude.*

Table 13 is a list of some of the observatories in the United States. Can you use the above information to determine their limiting magnitudes?

Reflecting telescopes use a concave mirror to gather enough light to enable viewers to see objects fainter than the sixth magnitude. A refracting telescope uses a glass lens to gather light in the same manner that a magnifying glass does. The glass lens is called the "objective" lens of the telescope.

Table 13.–Observatories

Observatory	Location	Telescope Lens Diameter	L.M.
Churchill Area H.S.	Pittsburgh, Pa.	9″	
Georgetown University	Washington, D. C.	13″	
U. S. Naval Observatory	Washington, D. C.	26″	
Allegheny Observatory	Pittsburgh, Pa.	30″	
Lick Observatory	Mt. Hamilton, Calif.	36″	
*Yerkes Observatory	Wilhome Bay, Wis.	40″	
Harvard University	Cambridge, Mass.	61″	
Palomar	Mt. Wilson, Calif.	100″	
Hale Telescope	Mt. Palomar, Calif.	200″	
* Largest refracting telescope of its kind in the world.			

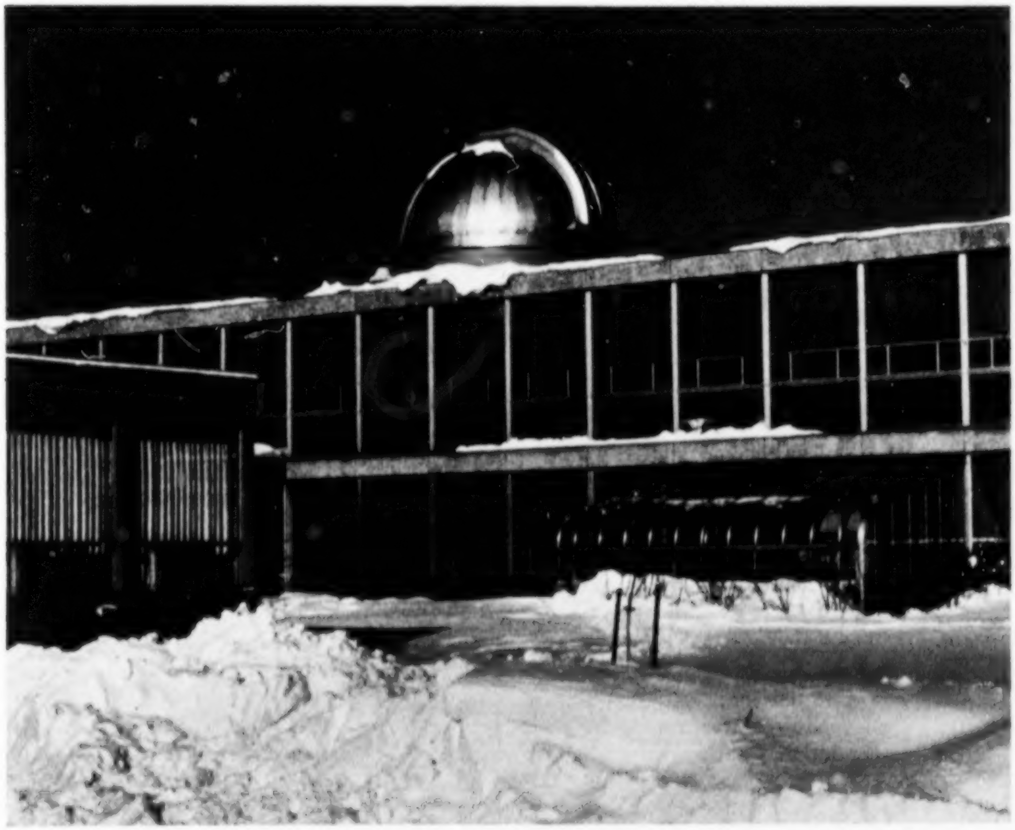


Figure 10. High school observatory in the Churchill area near Pittsburgh, Pennsylvania

Two Student Research Projects

1. The student is invited to investigate "quasi-stellars." What are they? How have they been detected? What is the significance of their discovery?

One reference is the May 25, 1964 issue of *Newsweek*.

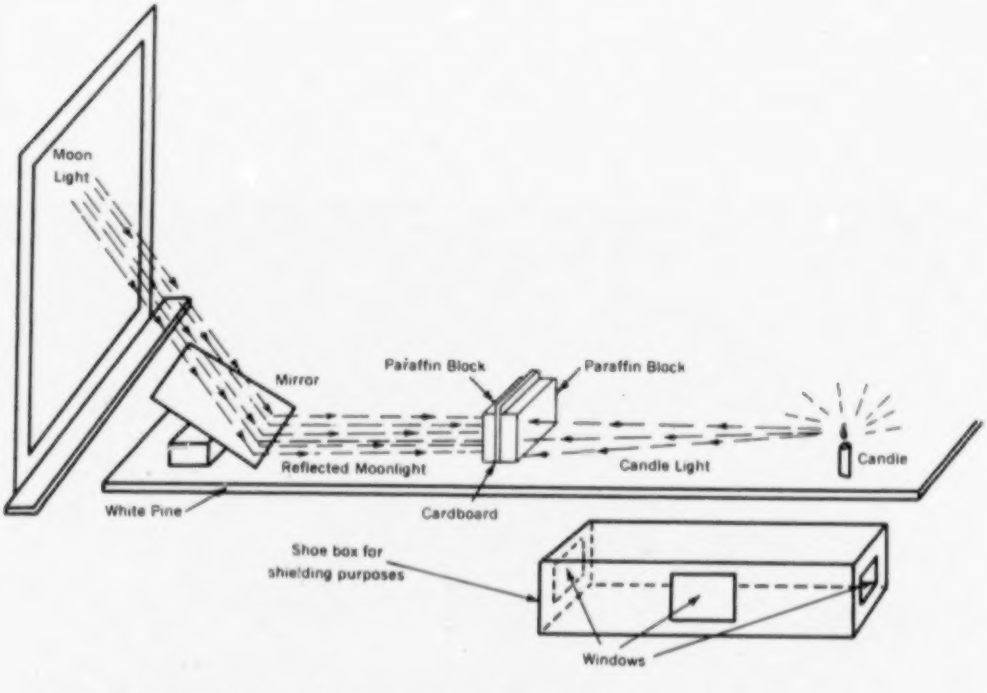
2. An individual laboratory experiment in photometry—the science of the measurement of light intensity.

Title: THE MOON'S MAGNITUDE

Objective: To determine the magnitude (brightness) of a full moon.

Apparatus:
- 1 plane mirror (highly reflective)
- 1 standard candle
- 1 meter stick
- 2 blocks of paraffin wax
- 1 piece of cardboard
- 1 1" x 3" x 72" piece of white pine
- 1 large shoebox (for shielding purposes)
- 1 block of wood (support for the mirror)

NOTE:—The magnitude of a standard candle at a distance of 1 meter = −14.2.


Moon Light
Mirror
Paraffin Block
Paraffin Block
Reflected Moonlight
Candle Light
Candle
White Pine
Cardboard
Shoe box for shielding purposes
Windows

Note: The magnitude of a standard candle at a distance of 1 meter = −14.2

Figure 11. Student photometer

Procedure: Place a piece of cardboard between two blocks of paraffin and turn one of the blocks so light will fall on its largest side. Notice the difference in contrast or shading when you look at one block and then the other. Examine Figure 11 and be satisfied that this contrast can be increased or diminished by moving the blocks of paraffin toward or away from the source of light.

NOTE TO STUDENT: This phenomena is often described using what is called the inverse square law. The brightness of the light varies inversely with the square of the distance. An object two feet away from a light receives one fourth as much light as an object one foot away.

If the blocks of paraffin are placed on the board where one block appears to have the same illumination as the other, the light striking the blocks are said to have the same intensity or brightness or illuminating power.

All other light must be excluded, therefore, a darkened room is necessary. A shoebox may be used as shown in Figure 11.

Stellar magnitude can be determined by using the following proportion.

$$\frac{\text{The magnitude of a candle}}{1\ \text{meter}^2} = \frac{\text{The magnitude of the Moon}}{S_c^2}$$

S_c^2 = The square of the distance in meters a candle is from the cardboard when the paraffin blocks appear to be equally illuminated.

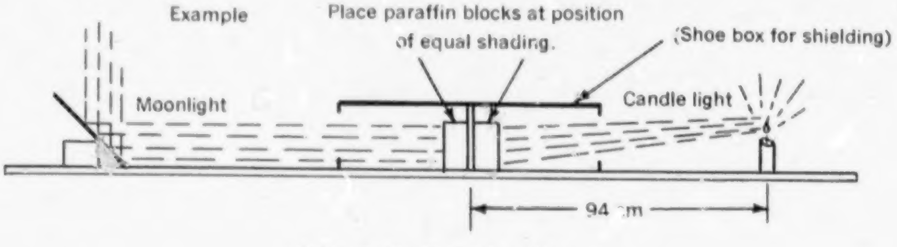


Figure 12. Sample trial

The meter stick measures the distance from the candle to the cardboard to be 94 cm. This is the equivalent of 0.94 m.

Hence

$$\frac{-14.2\ \text{magnitude}}{1\ \text{m}^2} = \frac{X}{(.94\text{m})^2}$$

X = the stellar magnitude of moon.

$X\ \text{m}^2 = (-14.2\ \text{magnitude})\ (.8836\text{m}^2)$

$X\ \text{m}^1 = (-12.547\ \text{magnitude})\ (\text{m}^1)$

Since the accepted stellar magnitude of the Moon is −12.6, our experiment shows an error of 0.42 percent which is relatively good considering the crudeness of our apparatus.

NOTE: The shoe box with slits cut in the ends was used to shield the paraffin blocks from any sources except those of the Moon and candle.

Try to perform this experiment in a dark room by catching the Moon's reflected light through a window. The shoe box will not be needed as a shield under these conditions.

Remember to position the mirror at such an angle so as to receive the maximum amount of reflected light.

S_c = distance of candle to paraffin blocks.

Table 14.–Student data table

Trial	S_c	S_c^2	X	Percent error
1				
2				
3				
Average				

Conclusion: Here you should analyze your data and give reasons for your results, good or bad. Can you think of a better way to conduct the experiment to increase your accuracy?

SOME MATHEMATICAL APPLICATIONS

Vectors and Angles

Most of science today would be impossible without numbers and mathematics. Space scientists and engineers often use numbers with which we are all familiar, such as decimals, fractions, mixed numbers, exponents, and of course letters to represent certain quantities. For example, the speed of a plane is given as Mach 2, or the speed of a booster is listed as Mach 20. This simply means the craft is travelling 2 or 20 times the speed of sound.

Decimals are often used to designate the brightness of celestial objects in terms of magnitude. The magnitude of the star Antares in the constellation of Scorpius is 1.2 and the magnitude of Rigel in the constellation of Orion is 0.3.

All of the numbers mentioned above are quantitative, that is, they represent certain quantities. These numbers are known as scalar quantities. A *scalar* is a number having magnitude only and has nothing whatsoever to do with direction.

There are times when the scientist must use one number to represent both quantity and direction.

A good example of this is in fixing the positions of points on the circumference of a circle. A line one unit long pointing east can represent a line from inside the center of the earth to a fixed point on the equator. Another line one unit long pointing due north represents a line from the center of the earth to the north pole.

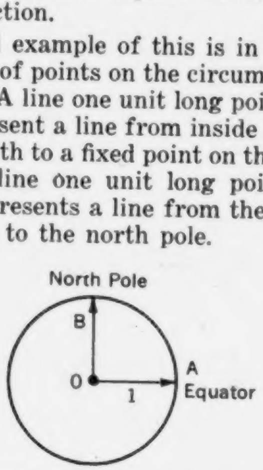


Figure 13. Earth's radii

Vectors are number pairs that have both magnitude and direction.

Radius $\overrightarrow{OA}$ is called a vector because it represents both magnitude and direction.

Vector $\overrightarrow{OA}$ is described as 1 unit East or 1 unit at 0°.

Vector $\overrightarrow{OB}$ is described as 1 unit North or 1 unit at 90°.

Now look at an Earth-Sun relationship again assuming the Earth's orbital path is nearly circular.

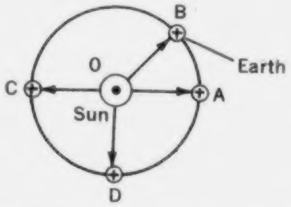


Figure 14. Vector diagram

$\overrightarrow{OA}$ = 1 A.U. at 0°

$\overrightarrow{OB}$ = 1 A.U. at 45°

$\overrightarrow{OC}$ = 1 A.U. at 180°

$\overrightarrow{OD}$ = 1 A.U. at 270°

Notice that the letter A denotes the position of the Earth on its orbit while the line OA represents its distance from the Sun. The point of the arrow denotes direction in figure 16.

Hence $\overrightarrow{OB}$ is read, "vector OB and represents a magnitude of 1 astronomical unit at an angle of 45°".

Now plot or draw the following vectors using figure 15 and using data in table 15.

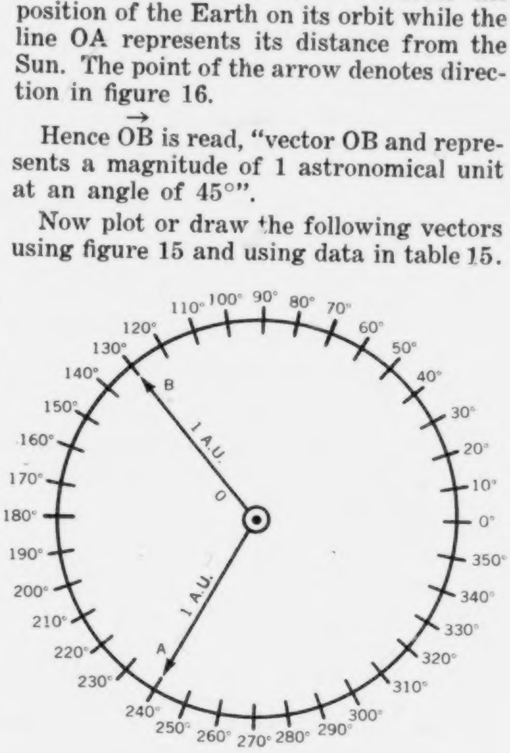


Figure 15. Vector radius

Table 15.–Vectors

OA = 1 A.U. 240°
OB = 1 A.U. 130°
OC = 1 A.U. 300°
OD = 1 A.U. 0°
OE = 1 A.U. 135°
OF = 1 A.U. 175°

Notice the vectors used above are equal in magnitude and vary in their direction. One must have the ability to plot vectors regardless of magnitude and direction. All that is needed is a protractor, a compass, and a ruler. The following problem illustrates an application of vector.

Retrograde Motion

What is retrograde motion? Can you explain retrograde motion in a clear, logical manner? The following is an attempt to explain retrograde motion using vectors.

The planets were called "Wanderers" due to their strange motions in the celestial sphere. Normally the planets move from the west to the east in relation to fixed stars when viewed from the Earth. However, there are times when one *will appear* to be moving from the east to the west. This phenomena is defined as *retrograde motion.*

You will need a compass, a protractor, sharp pencils, a 30°, 60°, 90° triangle, and a T-square. The procedure is as follows:

1. Tape a plain white piece of paper to a drawing board or some other smooth surface such as a table top or desk top.
2. Use a scale where 1¼″ equals 1 A.U. Then ⅛″ will represent the basic or scalar unit of length for our drawing. This means that 1 scalar unit = 0.1 A.U. and 10 scalar units = 1 A.U.
   1 A.U. = 1 astronomical unit = 92.9 million miles (approximately)
3. Construct two concentric circles. The larger circle should have a radius of 1 A.U. or 1¼″. The radius of the smaller circle should be .7 A.U. or ⅞″. The large circle represents the Earth's orbit about the sun and the small circle represents the orbit of Venus.
4. Fix the position of Earth and Venus so they are 180° apart. See figure 18. Figure 18 shows the normal movement of the Earth and Venus in a counterclockwise path about the sun as viewed from Polaris, the north star.
5. Now divide the orbit of the Earth into 12 monthly intervals of 30° each. Remember the annual period is the time for one complete revolution about a fixed point.

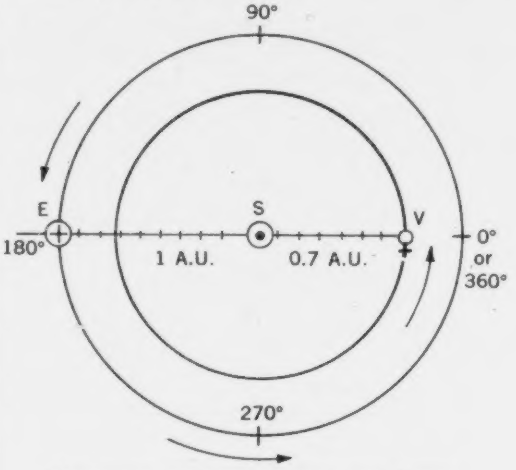


Figure 16. Orbits of Earth and Venus

6. Now refer to table 2 page 7 to obtain the sidereal period of Venus, or the time for Venus to complete one revolution. We can use a proportion here:

$$\frac{\text{period of Venus}}{\text{period of Earth}} = \frac{224.7 \text{ days}}{365.3 \text{ days}}$$

Let x = the period of Venus as compared to 12 Earth months.

$$\frac{x}{12 \text{ mo.}} = \frac{224.7 \text{ days}}{365.3 \text{ days}}$$

$$x = \frac{(224.7)\ (12 \text{ months})}{365.3}$$

$$x = 7.4 \text{ months (approximately)}$$

The annual period of Venus is 7.4 Earth months.

7. Now if we divide the orbit of Venus into 7.4 equal intervals, each interval would be $\frac{360^\circ}{7.4}$, or approximately 48.6° per interval.
   Round this off to 49° and use a protractor to divide Venus' orbit into monthly intervals of 49° each.
8. Figure 16 should now resemble figure 17 below in which the position of the planets are fixed at monthly intervals.

Tables 16 and 17 give positions of Venus and Earth during one year.

Notice that Venus in Figure 17 completes close to one and one half orbits while the Earth is completing one orbit. Position E_1 is the Earth's position in January when Venus is at superior conjunction at V_1.

E_6 is the Earth's position in June and this corresponds to V_6 which is the position of Venus in June.

A line from E_1 to V_1 represents the distance from Earth to Venus and the direction in January. Therefore line E_1V_1 is a vector quantity.

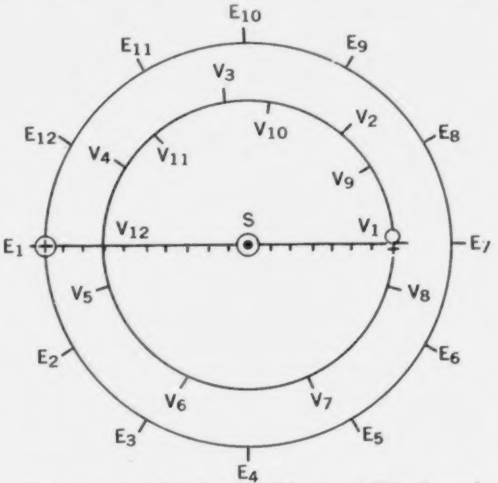


Figure 17. Monthly positions of Earth and Venus

Table 16.–Venus positions

Position	Angle
V_1	0°
V_2	49°
V_3	98°
V_4	147°
V_5	196° = 16° + 180°
V_6	245° = 65° + 180°
V_7	294° = 24° + 270°
V_8	343° = 63° + 270°
V_9	392° = 32° + 360°
V_{10}	441° = 81° + 360°
V_{11}	490° = 130° + 360°
V_{12}	539° = 179° + 360°

E_2V_2 = distance and direction of Venus in February, observed from the Earth.

9. Connect the positions of the planets Earth and Venus with straight lines at E_1 and V_1, E_2 and V_2, E_3 and V_3, and so on until one year of time has been completed. $\overrightarrow{E_1V_1}$, $\overrightarrow{E_2V_2}$, $\overrightarrow{E_3V_3}$, $\overrightarrow{E_4V_4}$, . . . are vectors representing the distances and directions of Venus from Earth as they move in their orbits.

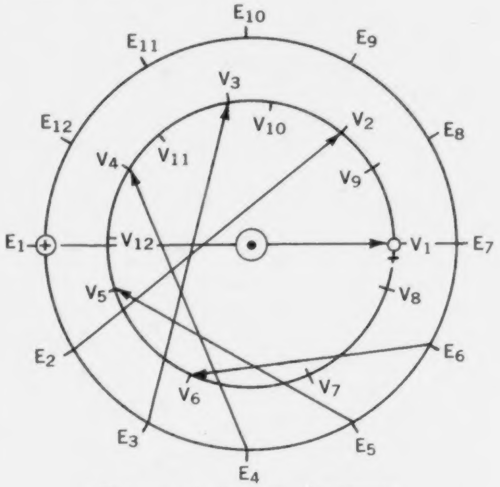


Figure 18. Vector distances

Table 17.–Earth positions from Sun

Position	Angle
E_1	180°
E_2	210°
E_3	240°
E_4	270°
E_5	300°
E_6	330°
E_7	360°
E_8	390°
E_9	420°
E_{10}	450°
E_{11}	480°
E_{12}	510°

Each vector represents the magnitude of distance and the direction of Venus from Earth at monthly intervals. NOTE: (This entire problem has been treated from a heliocentric standpoint. We must apply Hipparcus' and Ptolemy's geocentric theory at this time since Venus is being observed from Earth.)

10. Each vector has been measured individually and the statistics for each one has been tabulated and entered into a data table. See Table 18.

We must now plot each vector in turn using a geocentric or earth centered system. After each vector has been plotted in turn, as in Figure 19, the endpoints are joined by a smooth curve which traces the apparent path of Venus as viewed from the Earth. Notice the wandering or retrograde motion in Figure 19.

Table 18.–Vector coordinates

Vector	(Distance) Magnitude on A.U.	Direction in Degrees
E_1V_1	1.70 A.U.	0°
E_2V_2	1.65	38.5°
E_3V_3	1.60	76.0°
E_4V_4	1.50	112.8°
E_5V_5	1.33	151.0°
E_6V_6	1.18	186.0°
E_7V_7	0.95	222.0°
E_8V_8	0.74	239.7°
E_9V_9	0.50	282.0°
$E_{10}V_{10}$	0.33	292.0°
$E_{11}V_{11}$	0.33	280.0°
$E_{12}V_{12}$	0.49	289.0°
$E_{13}V_{13}$	0.73	315.4°
$E_{14}V_{14}$	0.95	348.4°
$E_{15}V_{15}$	1.17	321.0°
$E_{16}V_{16}$	1.36	419.0°

Table 18 gives both magnitudes (distance in A.U.) and directions of Venus from the Earth during 16 months.

Examine the above data? Can you arrive at any conclusions before plotting these data?

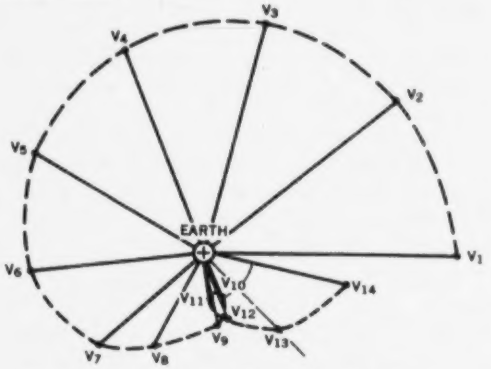


Figure 19. Retrograde motion of Venus

The dotted path illustrates the retrograde motion of Venus using vectors. The retrograde motion occurs because we are observing Venus from a planet that is revolving at a different rate. V_{10} and V_{11} are endpoints.

How many months after superior conjunction does retrograde motion begin?

The student should be able to show that the inferior planets retrograde near inferior conjunction. In general, a planet retrogrades when it is nearest the Earth.

CHARTING POSITIONS OF PLANETS

Figures 20 and 21, in conjunction with Table 19, enable us to ascertain quickly the approximate location of ☿ , ♀ , ⊕ , ♂ , ♃ , and ♄ at any time in the interval 1400-2400 A.D. (The symbols stand for six planets in our solar system; namely, Mercury, Venus, Earth, Mars, Jupiter, and Saturn.) See pages 22-25

In Figure 20 the orbits of the terrestrial planets, indicated by their symbols, are drawn to scale but, by necessity, in the same plane.[5]

In both figures, the monthly position of the Earth is indicated while the decimals

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[5] Walter Bartky, *Highlights of Astronomy*, (Chicago: University of Chicago Press, 1935), p. 168.

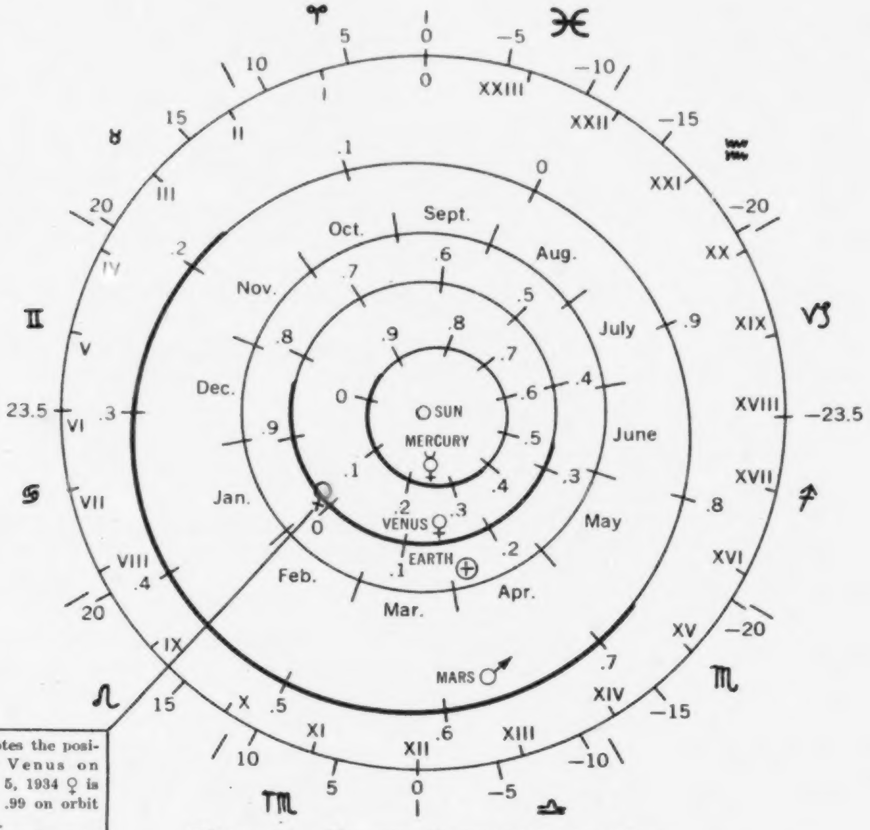
0, 0.1, 0.2, up to 0.9 designate orbital positions of the remaining planets, the numbers 0 and 0.5 defining perihelion and aphelion, respectively. The order of the decimals indicates the direction of the motion, and the arc between the points associated with two successive decimals is the path described by the planet in 1/10 its period of revolution; consequently, given the length of time that has elapsed since a perihelion passage, it is possible by means of these markings to locate the object in either Figure 20 or Figure 21.

The decimal corresponding to the planet's position at any specified time is obtained from Table 19 by a simple addition of numbers associated with the day of the month, the month, and the units, tens, and hundreds in the year number.

An example illustrates the method:

Suppose we seek the position of the planet Venus on February 5, 1934. The day of the month is 5, the month February, the units in the year number are 4, the tens are 3, and the hundreds are 19. From Table 19 we obtain certain numbers associated with the aforementioned, which we tabulate and sum as follows:

		Associated Number
Day of the month	5	0.01
Month	February	.72
Units in year number	4	.50
Tens in year number	3	.76
Hundreds in year number	19	0.00
	Total	1.99



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10
15
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23.5
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I
II
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IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
XXI
XXII
XXIII
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
SUN
MERCURY
☿
VENUS ♀
EARTH ⊕
MARS ♂
.1
.2
.3
.4
.5
.6
.7
.8
.9

This denotes the position of Venus on February 5, 1934 ♀ is placed at .99 on orbit of Venus.

Figure 20 . Mercury, Venus, Earth, and Mars

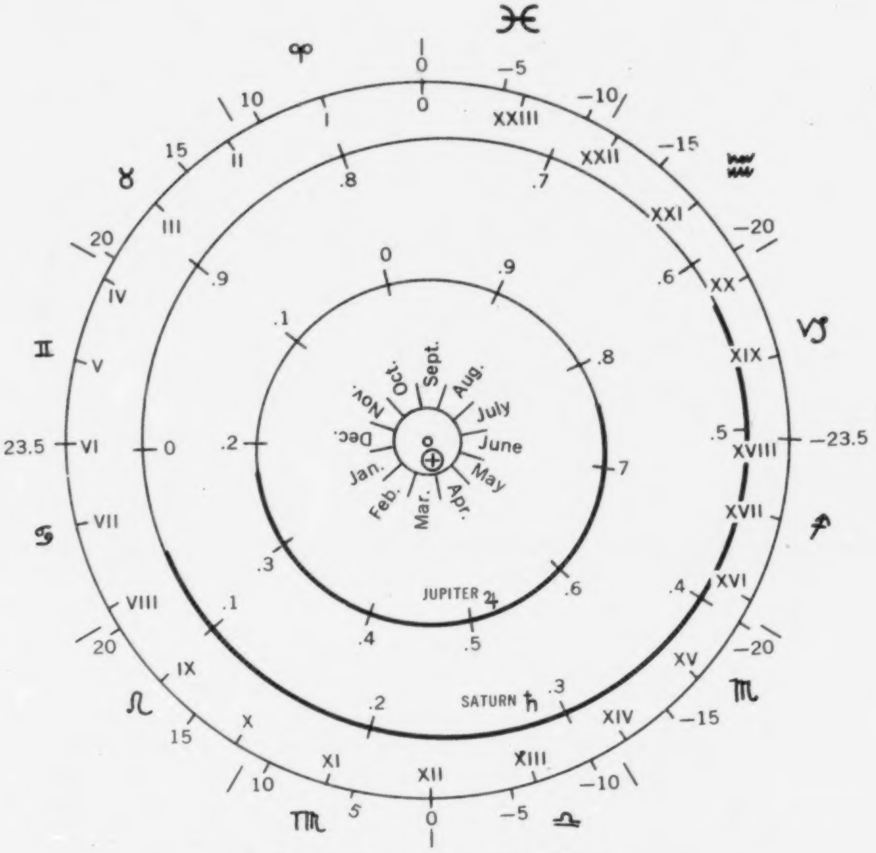
Walter Bartky, Highlights of Astronomy (Chicago: The University of Chicago Press, 1935), p. 169.

We disregard the number to the left of the decimal point and retain only the decimal part, i.e., 0.99. The point corresponding to 0.99 on the orbit of Venus in Figure 20 represents the position of this planet on February 5, 1934, while the date itself determines the location of the Earth. It so happens that these two points, along with the central point (the Sun), are in a straight line in the order: Sun, Venus, Earth.

Suppose the next date is November 18, 1934. From Table 19 we find for Venus:

		Associated Number
Day of month	18	0.08
Month	November	.94
Units in year number	4	.50
Tens in year number	3	.76
Hundreds in year number	19	0.00
	Total	2.28

We place Venus on the point corresponding to the decimal 0.28 and the Earth on a position corresponding to November 18, to discover that these two planets are again in a line with the sun but now the order is Venus, Sun, Earth.


♓
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♒
23.5
−23.5
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
XXI
XXII
XXIII
Sept.
Aug.
July
June
May
Apr.
Mar.
Feb.
Jan.
Dec.
Nov.
Oct.
JUPITER ♃
SATURN ♄

Figure 21 . Jupiter and Saturn

Walter Bartky, Highlights of Astronomy (Chicago: The University of Chicago Press, 1935), p. 170.

In analogous fashion we find for Mercury on March 6, 1934:

		Associated Number
Day of month	6	0.06
Month	March	.96
Units in year number	4	.61
Tens in year number	3	.56
Hundreds in year number	19	0.00
	Total	2.19

On placing Mercury at 0.19 and the Earth at March 6 in Figure 20, we note that these two planets are in a line with the Sun. The conjunction is seen to have been inferior, for Mercury lay between the Earth and the Sun. Similarly, Figure 20 plus Table 19 informs us that on January 20, 1934, Mercury was at superior conjunction.

Find Jupiter for May 8, 1917.

Orbital motion in Figure 21 of Jupiter and Saturn is so slight during the course of a month that we disregard the day of the month; and we find for Jupiter:

		Associated Number
Month	May	0.64
Units in year number	7	.59
Tens in year number	1	.84
Hundreds in year number	19	0.00
	Total	2.07

Note above that Jupiter, Sun, and Earth are on a line in the order named.

Table 19.—Decimals for planets

Day of Month (Gregorian Calendar)

Day of month	1	4	7	10	13	16	19	22	25	28	31
Mercury	0.00	0.03	0.07	0.10	0.14	0.17	0.20	0.23	0.27	0.31	0.34
Venus	.00	.01	.03	.04	.05	.07	.08	.09	.11	.12	.13
Mars	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.04

Month

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mercury	0.29	0.64	0.96	0.31	0.65	0.00	0.35	0.70	0.06	0.40	0.75	0.09
Venus	.58	.72	.85	.99	.12	.26	.39	.53	.67	.80	.94	.07
Mars	.90	.95	.99	.03	.07	.11	.15	.20	.25	.29	.34	.38
Jupiter	.61	.62	.62	.63	.64	.65	.65	.66	.66	.67	.68	.68
Saturn	0.49	0.49	0.49	0.50	0.50	0.50	0.50	0.51	0.51	0.51	0.52	0.52

Year—Units

	0	1	2	3	4	5	6	7	8	9
Mercury	0.00	0.15	0.30	0.46	0.61	0.76	0.91	0.06	0.22	0.37
Venus	.00	.63	.25	.88	.50	.13	.75	.38	.00	.63
Mars	.00	.53	.06	.59	.13	.66	.19	.72	.25	.78
Jupiter	.00	.08	.17	.25	.34	.42	.51	.59	.67	.76
Saturn	0.00	0.03	0.07	0.10	0.14	0.17	0.20	0.24	0.27	0.31

Walter Bartky, Highlights of Astronomy (Chicago: University of Chicago Press, 1935), p. 171.

Year—Tens

	0	1	2	3	4	5	6	7	8	9
Mercury	0.00	0.52	0.04	0.56	0.08	0.60	0.12	0.64	0.16	0.68
Venus	.00	.25	.51	.76	.01	.27	.53	.78	.04	.29
Mars	.00	.31	.63	.95	.27	.58	.90	.21	.53	.85
Jupiter	.00	.84	.69	.53	.37	.22	.06	.90	.74	.59
Saturn	0.00	0.33	0.68	0.02	0.35	0.70	0.04	0.38	0.72	0.06

Year—Hundreds

	14	15	16	17	18	19	20	21	22	23
Mercury	0.02	0.22	0.41	0.61	0.80	0.00	0.20	0.39	0.59	0.78
Venus	.29	.82	.36	.91	.45	.00	.55	.09	.64	.18
Mars	.18	.34	.51	.67	.84	.00	.16	.33	.49	.66
Jupiter	.85	.28	.71	.14	.57	.00	.43	.86	.29	.72
Saturn	0.02	0.42	0.82	0.21	0.61	0.00	0.39	0.79	0.18	0.58

Table 20.–Evening and morning stars

	Decimal	Right Ascention	Declination	Sun	Description
Sun		5^h15^m	17°		
Mercury	0.28	7 00	24°		Evening Star
Venus	.56	2 30	13		Morning Star
Mars	.20	4 15	12		Morning Star
Jupiter	.52	12 50	−4		Evening Star
Saturn	0.66	22 00	−13		Morning Star

THE FUTURE

Nothing is Impossible

Man has not yet built the "time capsule" that will take him into the future. We must be content to look into the future through such eyes as those of Copernicus, Newton, and Einstein. These men unlocked the secret of looking into the future with such keys as mathematics and physics.

The junior high school student of today who is keenly interested in the future must prepare himself now. History, Biology, Chemistry, Physics, Algebra II, Trigonometry, Advanced Mathematics, English, and French are courses which require much of the student. The student who accepts the challenge to work and study will discover there are no courses which are more rewarding.

Scientists are using space probes to look far out into space and make observations. To do this, they must answer the questions of why, when, where, how and who.

1. Why will we send the space probe?
2. When should we send the space probe?
3. Where will we send the space probe?
4. How will we send the space probe?
5. Who will send the space probe?

Problem:

Select some future date as the time for a space probe to a particular member of the solar system. Now try to fix the position of the planet in question at the time of launching and also its position at time of interception, using a diagram such as Figure 17. Investigate the laws of Kepler and Newton to determine how much thrust is needed to achieve the necessary escape velocities to go and return.

A knowledge of algebra and physics will assist the student in solving the following problem.

Hypothetical Problem

A 100 pound spacecraft is to be launched toward Venus on July 9, 1965, for the purpose of conducting approximately eight experiments.

a. Fix the position of Venus at the time of launch.

b. How long will it take the spacecraft to get there?

c. Approximately where will Venus be at the time the spacecraft approaches Venus' position?

d. What is the escape velocity required to leave Venus and return to Earth?

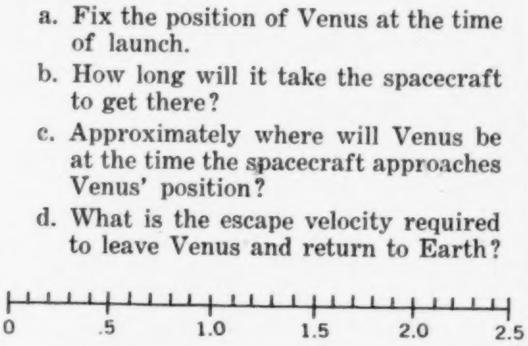


Figure 22. Scale in astronomical units

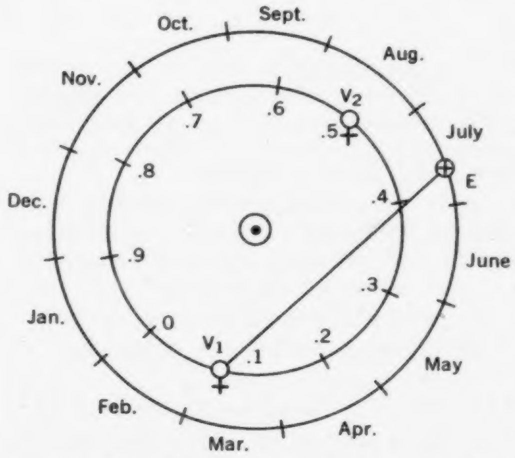


Figure 23. Positions of Earth and Venus

Solution

A. To fix the position of Venus at time of of launch:

Use Figure 20 to locate Venus at time of launch.

Place Earth at the position representing July 9.

Use chart to locate Venus at time of launch.

		Associated Number (approximately)
day of month	9	0.04
month	July	0.39
units in year number	5	0.13
tens in year number	6	0.53
hundreds in year number	19	0.00
	Total	1.09

Position Venus at 0.09 on its orbit in Figure 20.

Draw $\overrightarrow{EV}$ and compare its length to the scale in Figure 15.

$\overrightarrow{EV} = 1.5$ A.U.

B. How long will it take the spacecraft to get there?

1. Assume the Earth's escape velocity to be 7 mi/sec. (7 miles per second)

2. Since Distance

$$= \text{velocity X time} \qquad (1)$$

$$\frac{\text{Distance}}{\text{Velocity}} = \text{time} \qquad (2)$$

The distance $\overrightarrow{EV}$ =

$$\left(\frac{1.5\text{ A.U.}}{1}\right)\left(\frac{92{,}900{,}000\text{ mi}}{1}\right) \qquad (3)$$

$$\overrightarrow{EV} = 139{,}350{,}000\text{ mi} \qquad (4)$$

$$\text{time} = \frac{\text{Distance}}{\text{velocity}} \qquad (5)$$

$$\text{time} = \frac{139{,}350{,}000\text{ mi}}{7\text{ mi/sec}} \qquad (6)$$

Remember when dividing by fractions to invert the divisor and multiply.

Equation (6) then becomes

$$\text{time} = \frac{139{,}350{,}000\text{ mi}}{1} \text{ X } \frac{1\text{ sec}}{7\text{ mi}}$$

$$\text{time} = 19{,}907{,}000\text{ sec. (aprox.)}$$

time =

$$\left(1.99 \times 10^{7} \text{ sec}\right)\left(\frac{1 \text{ hour}}{3.6 \times 10^{3} \text{ sec}}\right)$$

$$\text{time} = 0.555 \times 10^{4} \text{ hours}$$
$$= 5.55 \times 10^{3} \text{ hours}$$
$$\text{time} = 2.31 \times 10^{2} \text{ days}$$
$$= 7.7 \text{ months}$$

C. Approximately where will Venus be at the time the spacecraft nears the planet?

1. Since 7.7 months have lapsed since the spacecraft was launched, the date is now March 2, 1965.

	Associated Number
day of month ---- 2	0.00
month ----- March	0.85
units in year number ------- 5	0.13
tens in year number ------- 6	0.53
hundreds in year number ------ 19	0.00
Total ----	1.51

The new position of Venus is at V_2 in figure 23. What conclusions can you draw concerning the initial problem?

The balance of the problem is left for the student.

A challenge for the better student: When will be the most favorable time during the next two years to send a space probe to Mars?

CONCLUSION AND PROJECTION

The discussion and study of orbiting bodies have purposely been limited to circular orbits. The circular orbits which we have discussed have an eccentricity of zero, or $e = 0$.

Further study of Kepler's Laws will reveal the true nature of the orbiting paths of the planets as they travel around the sun. A study of conic sections will reveal the possible curves or paths a satellite may have. These topics are generally found in high school mathematics, physics, and astronomy courses. The different paths are described as being those of a circle, ellipse, parabola, or hyperbola. Each of these has a path which can be described by an algebraic equation.

The student willing to spend the time and work will learn of the method used to classify these different paths or curves. He will learn the meaning of eccentricity.

We have seen old principles become the basis for new ideas. Archimedes and Galileo, Einstein and Goddard have given us the tools with which to write new history—Yes—From HERE, WHERE . . .?

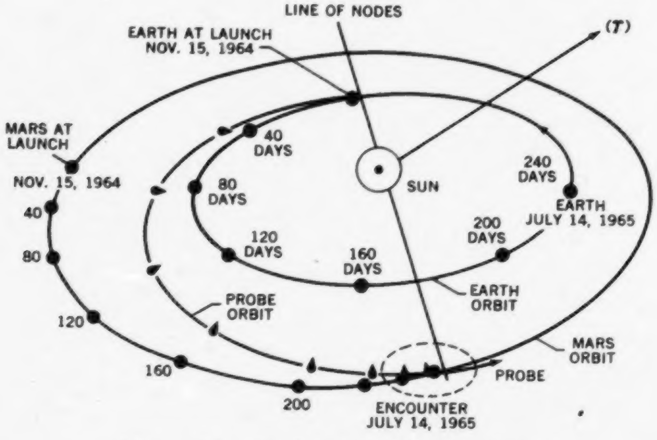
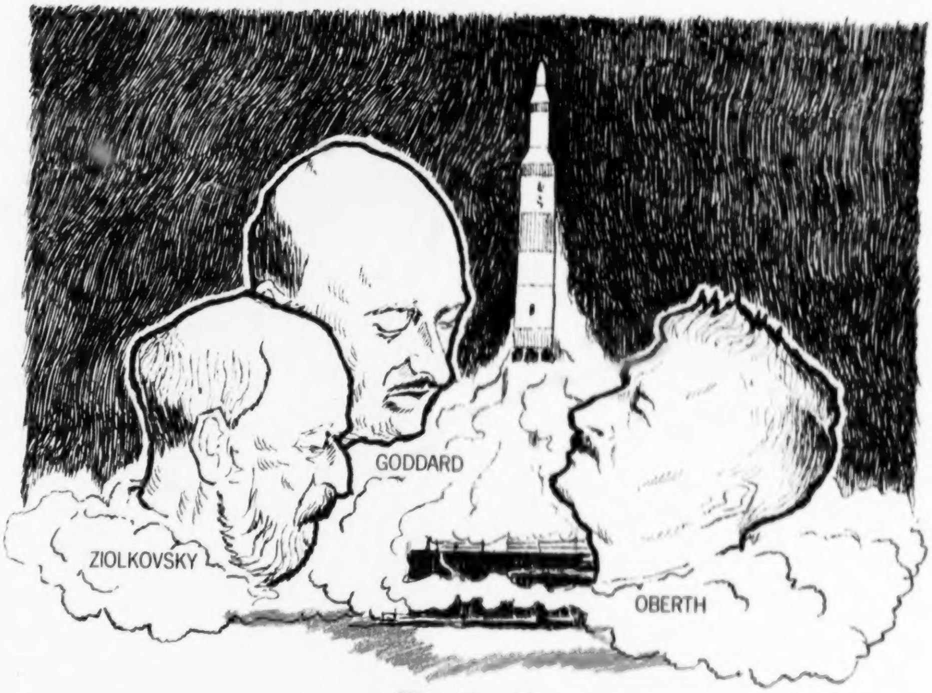

LINE OF NODES
EARTH AT LAUNCH NOV. 15, 1964
(T)
MARS AT LAUNCH
NOV. 15, 1964
40 DAYS
80 DAYS
120 DAYS
160 DAYS
200 DAYS
240 DAYS
SUN
EARTH JULY 14, 1965
EARTH ORBIT
40
80
120
160
200
PROBE ORBIT
MARS ORBIT
PROBE
ENCOUNTER JULY 14, 1965

Figure 24. Typical 1964 Mars trajectory



Chapter II

GETTING INTO SPACE

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ABOUT THIS CHAPTER

Our orbiting spacecraft have enabled us to send the most delicate scientific instruments into outer space. Linked to the earth-bound scientist via electronic signals, these laboratories are providing us daily with new data, extending our knowledge and horizons.

The advent of the space age was made possible by the development of the rocket engine. It was Dr. Robert H. Goddard, an American, Dr. Hermann Oberth, a German and Konstantin E. Ziolkovsky, a Russian, working independently, who helped to make one of man's oldest dreams come true—and in your life time!

The purpose of this chapter is to answer one common question, "How does a rocket push itself through outer space?"

You will find it an interesting and challenging subject which will make news about the space program even more meaningful.

EARLY ROCKETS

We usually consider rockets as products of the twentieth century. Actually, the invention of the first rocket is credited to the Chinese in about the eleventh century. In the year 1232 it is known that rockets were used during the Mongol siege of the Chinese city of Kaifeng. In 1280 an Arabian named Hassan Alrammah wrote a manuscript which indicated how to build rockets. Knowledge of how to make and use rockets spread rapidly from country to country. An Italian engineer, Joanes de Fontana, in 1405 wrote a book in which he described a rocket car which could be used in battle as a battering-ram. In Italy from the eighteenth century to the present day rockets found their principal application as a source of entertainment. The gigantic displays of Italian fireworks have been famous throughout the world.

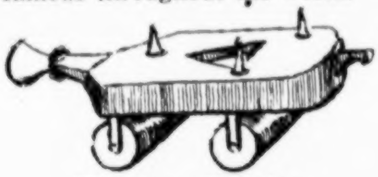


Figure 1. Rocket car

During the latter part of the eighteenth century the British army stationed in India was defeated by the Indian rocket corps. After this surprising defeat the British attempted to build their own rockets. In this attempt they were successful due to the efforts of William Congreve. Later Congreve's rockets were credited with victorious battles against Denmark, France, and Prussia. "The rockets red glare," seen by Francis Scott Key, author of "The Star Spangled Banner," during the British attack on Fort McHenry in Baltimore harbor during the War of 1812 was due to Congreve's rockets. Rockets saw service in the Mexican War of 1847, but thereafter artillery replaced rockets in warfare due to its greater accuracy.

After the turn of the century, rocketry had a dramatic rebirth as a result of the work of three men—all working independently, Dr. Robert H. Goddard, an American, Dr. Hermann Oberth, a German, and Konstantin E. Ziolkovsky, a Russian.

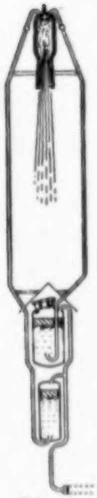


Figure 2.

Dr. Goddard's first liquid-fuel rocket—1926

In 1903 Ziolkovsky, who was a schoolteacher, wrote an article which considered for the first time the use of rocket propulsion power to travel to outer space.

In March of 1926 Dr. Goddard launched the world's first liquid propellant rocket from a farm near Auburn, Massachusetts. As a result of this and other early achievements, he is now considered "The Father of Modern Rocketry."

As Dr. Goddard worked in the United States, Dr. Oberth worked independently in Germany. In 1937 the German rocket research center in Peenemuende was established. It was in this place that the V–2 rockets of World War II were built.

……

Exercise:

Who are some current scientists in the field of rocketry? Consult your latest encyclopedia and yearbooks.

……

THE ROCKET ENGINE

A rocket is a special kind of jet engine. A jet, which is a fast moving stream of gas, is produced by the burning of the fuel in the engine. Escaping from the rear, the jet propels the rocket forward.

The basic difference between the rocket engine and jet engines is that rocket engines carry not only their fuel, but also their own oxygen or oxidant needed for

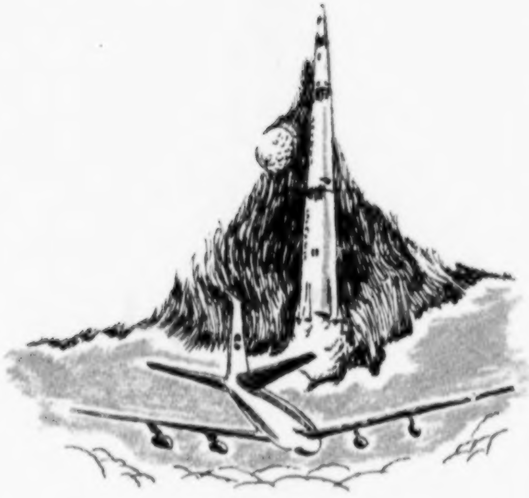


Figure 3.

the burning of the fuel. Jet engines must use the oxygen found in the air. This difference clearly limits jet engines to altitudes where their is an adequate supply of oxygen. However, rocket engines can go to any altitude, even to outer space where there is no oxygen.

To see what one kind of rocket engine looks like let us look at Figure 4. We can see that it has a rather simple structure. Basically, a rocket engine consists of three major parts, a propellant storage tank, a combustion chamber, and a nozzle. In the combustion chamber the propellants (which include both the fuel and oxidizer) are brought together and allowed to react. As a result of this reaction, heat energy and gas molecules are rapidly released through the nozzle, propelling the rocket forward. The shape and size of the nozzle are important in a rocket engine because they, as well as the propellant, determine the speed at which the rocket will travel.

There are two general types of rocket engines used today. They are the monopropellant and the bipropellant rocket engines. The monopropellant rocket engine has only one propellant storage tank. In this one tank are kept both the fuel and the oxidizer which have been carefully premixed. Figure 4 shows such an engine. The bipropellant rocket engine has two tanks in which the fuel and oxidizer are stored separately as in Figure 5.

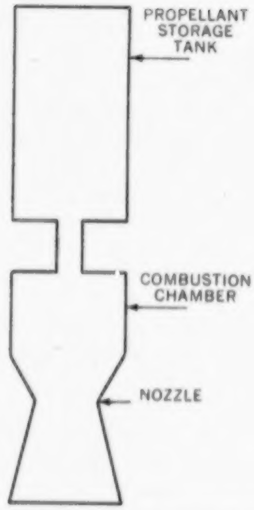


Figure 4. Monopropellant rocket engine

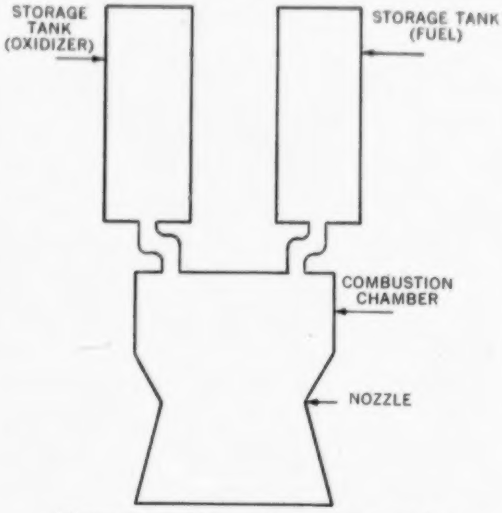


Figure 5. Bipropellant rocket engine

Each type of rocket engine has its advantages and disadvantages. The advantage of a monopropellant engine lies in its simplicity. Its disadvantage lies in the danger of its operation because the ignition of its premixed fuel and oxidizer is difficult to control.

The bipropellant engine is safer to operate and gives a more efficient performance even though the fuel and oxidizer must be separately controlled.

There are two kinds of propellants, solid and liquid. The solid propellants used in rockets many centuries ago consisted chiefly of gunpowder. Today, most of the large rockets use liquid propellants. Liquid oxidizers include hydrogen peroxide, nitric acid, and liquid oxygen. The most common liquid fuels used along with the liquid oxidizers are alcohol, kerosene, and aniline.

……

Exercise:

In a chemistry textbook find the chemical formulas for aniline, nitric acid, hydrogen peroxide, ethyl alcohol, and methyl alcohol. What element do all of these substances have in common?

……

Liquid propellants can be used in either mono- or bipropellant rocket engines. Solid propellants, however, can only be used in monopropellant rockets because the fuel and oxidizer must be premixed.

So far you have seen how a rocket engine differs from jet engines; you have also learned about rocket fuels. Let us now turn our attention to some of the mathematics of the way a rocket engine is propelled, and how the rocket engine's performance is measured.

THE MATHEMATICS OF ROCKET PROPULSION

The propulsion of a rocket is explained by Newton's third law of motion which states that for every action there is a reaction equal in size and opposite in direction.

……

Experiment: Demonstration of Newton's Third Law of Motion

Materials: One pair of roller skates
Several bricks or large wooden blocks

Procedure:
(a) Put on skates and stand on level floor with feet close together holding one brick or wooden block.
(b) Throw the brick or block directly forward.
(c) Measure the distance that you moved noting also the direction.
(d) Repeat steps a, b, and c, but this time throw two bricks or blocks in succession.
(e) Measure the distance and direction that you moved this time.

Results:
(a) In what direction did you move after you threw the objects?
(b) How far did you move after you threw one brick or block?
(c) How far did you move after you threw two bricks or blocks in succession?

Conclusions:
(a) The throwing of the bricks or blocks represented the "action" part of Newton's third law. What was the "reaction"?
(b) How do you account for the difference in the distance moved in parts (b) and (d) in the procedure above?
(c) What do you think would happen if you threw two bricks out at once instead of in succession? Try it.

……

Have you ever tried moving rapidly from the back to the front of a small rowboat while it's in the water? If you did, you probably noticed that the boat moved suddenly in a direction opposite to the direction in which you were moving. The movement of the boat was the "reaction" to your movement, which was the "action". This is an example of Newton's third law of motion. The faster that you move backward in the boat, the faster the boat will be thrust forward in the water. In

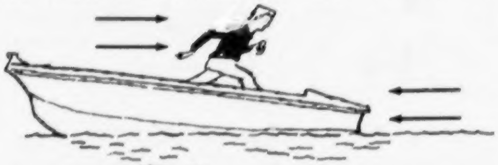


Figure 6. Newton's third law

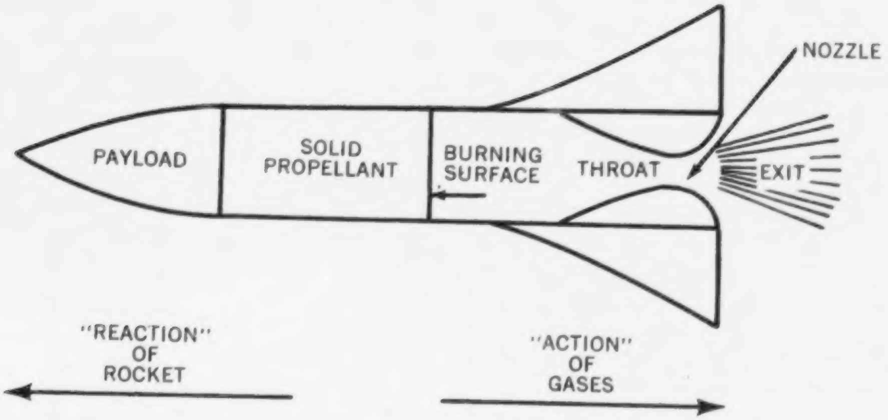


Figure 7. Simple solid propellant rocket

other words the thrust or "reaction" depends in part upon the velocity or speed of the "action."

Does anything else effect the thrust or "reaction"? Yes. The mass of the moving object also influences the thrust. By the mass of an object is meant the heft or bulk of the object, not the weight. Mass is a measure of the quantity of the material present. It is independent of weight. Weight is the pull of gravity on mass. If there is no gravity, there is no weight, but there is mass.

Many people mistakenly believe that a rocket is propelled through the air by its exhaust gases pushing against the outside air. Nothing could be further from the truth. If this belief were true, it would not be possible for rockets to travel in outer space, since there is no air against which to push. In fact rockets travel better where there is no air for there is less resistance to the rocket's flight.

If the rocket gases do not push against the outside air to propel the rocket forward, what do they push against? They simply push against the rocket and propel it in the opposite direction to which they are moving. Note the similarity between this situation and that of the rowboat mentioned earlier.

Let us now consider some of the mathematics of propulsion of thrust. For calculating the thrust developed in a rocket engine, the following equation could be used:

Carl Besserer and Hazel Besserer, Guide to the Space Age (Englewood Cliffs, N.J.: Prentice-Hall, 1959).

$$F = \frac{W\,v}{g} + (P_e - P_a)\,A_e$$

where F = the thrust in pounds
v = the velocity in feet per second
P_e = the pressure of the rocket gases at the exit of the nozzle in pounds per square inch
A_e = the area of the exit nozzle in square inches
P_a = the pressure of the atmosphere surrounding the rocket in pounds per square inch
W = the rate of discharge of the gas or liquid jet in pounds per second
g = 32.2 feet per second per second (gravitational acceleration).

Using this as a standard thrust equation let us work a few problems.

Example 1:

A rocket gives off exhaust gas at the rate of 10 lb. per second and at a pressure of 15 lb. per square inch. The gas is moving at a velocity of 1000 feet per second. The area of the exit nozzle is 50 square inches. What is the thrust of the rocket if the pressure of the surrounding atmosphere is approximately 15 lb. per square inch?

$$F = \frac{W v}{g} + (P_e - P_a) A_e$$

We know from the problem that the rocket gives off exhaust gas at the rate of 10 lb. per second; therefore, $W = 10$. The rocket exhaust pressure is given as approximately 15 lb. per square inch; therefore, $P_e = 15$. The pressure of the atmosphere is given as 15 lb. per square inch; therefore, $P_a = 15$. The velocity, v, is given as 1000; g is taken as 32.2; and the area of the exit nozzle, A_e, is given as 50.

Now by substituting the appropriate values in the equation we have:

$$F = \frac{(10)\ (1000)}{32.2} + (15 - 15)\ (50)$$

$$F = \frac{10{,}000}{32.2} + 0^*$$

$$F = 310.55 \text{ lb. thrust}$$

Example 2:

A water sprinkler discharges water at the rate of 1 lb. per second. The velocity of the water as it leaves the sprinkler is 32.2 feet per second. What is the thrust of the sprinkler assuming that the exit pressure of the water is approximately the same as the pressure of the surrounding atmosphere?

Here again by substituting in the thrust equation we get

$$F = \frac{(1)\ (32.2)}{32.2} + 0^*$$

$$F = 1 \text{ lb. thrust}$$

*Note: This term totals 0 in these problems because $P_a = P_e$; therefore, $P_e - P_a = 0$. For example, if $P_a = 15$ and $P_e = 15$, then by substitution $15 - 15 = 0$.

……

Exercises:

A–1. A rocket gives off exhaust gas at the rate of 100 lb. per second and at a pressure of 25 lb. per square inch. The gas is traveling at a velocity of 7500 feet per second. The pressure of the surrounding atmosphere is 15 lb. per square inch, and the area of the exit nozzle is 50 square inches. What will be the thrust of the rocket?

A–2. Repeat the above exercise but this time take the pressure in the upper atmosphere to be 1.5 lb. per square inch. What will be the thrust of the rocket now?

A–3. A garden hose discharges water at the rate of 2 lb. per second. The velocity of the water as it leaves the nozzle of the hose is 60 feet per second. What is the thrust of the garden hose if the exit pressure of the water is approximately the same as the pressure of the atmosphere?

A–4. Look up Sir Issac Newton in some reference books. What other contributions to science did he make besides his laws of motion?

……

DETERMINING HOW WELL A ROCKET ENGINE PERFORMS

Mathematics is used also in finding out how well a rocket engine is performing. With regard to the performance of a rocket there are several yardsticks for such measurement. One is horsepower; another is specific impulse; still another is mass ratio.

Horsepower

Horsepower is defined as a rate of doing work equal to 550 foot-pounds per second. Another way of expressing this is that one horsepower is equal to the amount of work done in one second by moving 550 pounds one foot or, conversely, the amount of work done in one second by moving one pound 550 feet. In space vehicles we can use miles per hour which is a larger unit than feet per second. Using this unit we can redefine horsepower as the amount of work done in one hour by moving 375 pounds one mile, or conversely, by moving one pound 375 miles in one hour. Can you figure out how we got 375 mile-pounds per hour from 550 foot-pounds per second? Try figuring it out.

$$\text{Hint: } \frac{\text{ft. lb.}}{\text{sec.}} \times \frac{\text{sec.}}{\text{hour}} \times \frac{\text{miles}}{\text{feet}} = \frac{\text{mile-lb.}}{\text{hour}}$$

Mathematically, a formula for horsepower can be written

$$\text{H. P.} = \frac{\text{Thrust (in lb.)} \times \text{Speed of Rocket (in m.p.h.)}}{375}$$

By substituting in this formula it can be seen that if a rocket travels at 375 miles per hour, the horsepower will be equal to the thrust of the engine.

$$\text{H.P.} = \frac{\text{Thrust} \times 375}{375}$$

$$\text{H.P.} = \text{Thrust}$$

What will be the horsepower when the rocket is traveling at 750 miles per hour? Substituting again in the formula we get

$$\text{H.P.} = \frac{\text{Thrust} \times 750}{375}$$

$$\text{H.P.} = 2 \times \text{Thrust}$$

Here, the horsepower is equal to two times the thrust. Thus, it can be readily seen that the horsepower of a rocket engine changes with the speed at which it is traveling. Consequently, horsepower is *not a realistic* way of measuring a rocket's performance. It can only give us a way to describe it. See Chapter III page 10.

Exercises:

B–1. What would be the horsepower of a rocket engine having a thrust of 5000 lb. when it is traveling at a speed of 750 miles per hour?

B–2. What would be the thrust of a rocket engine while traveling at a speed of 375 miles per hour and developing 3000 horsepower?

B–3. A rocket is traveling at the rate of 1500 miles per hour. At this speed it is giving off exhaust gas at the rate of 150 pounds per second at an exhaust pressure of 15 lb. per square inch. The gas is traveling at a velocity of 10,000 feet per second. The surrounding atmosphere is 10 lb. per square inch. The area of the exit nozzle is 50 square inches. What horsepower is the rocket engine developing? (HINT: Use standard thrust equation first.)

••

Specific impulse

Another method of measuring rocket performance is by determining the *specific impulse* which is defined as the amount of propellant that has to be burned per second in order to maintain a thrust of a given amount. More specifically the specific impulse is defined as the thrust a rocket will produce when the gas is coming out of the exit nozzle at the rate of one lb. per second. Mathematically stated

$$I_{sp} = \frac{F}{W}$$

where I_{sp} = specific impulse, in seconds
F = thrust of rocket, in pounds
W = weight of propellant used per second

Example 3:

What would be the specific impulse of a rocket engine which has a thrust of 10,000 pounds and uses its propellant at the rate of 50 pounds per second?

By substitution in the above formula we get

$$I_{sp} = \frac{10{,}000}{50}$$

$$I_{sp} = 200 \text{ seconds}$$

Normally, the higher the specific impulse the more efficient is the rocket engine. The chemical rocket engines used today have specific impulses much more efficient. With the advent of newer propulsion systems higher specific impulses can be expected.

••

Exercises:

C–1. What would be the specific impulse of a rocket engine like the Delta which has a thrust of 170,000 lb. and uses its propellant at the rate of 850 lb. per second.

C–2. The specific impulse of an engine is 275 seconds, and the engine has a thrust of 27,500 lb. What would be the rate at which the propellant will be used?

C–3. A rocket engine develops 2000 horsepower at 750 miles per hour while using 4 lb. of propellant per second. What specific impulse does the rocket engine have?
(HINT: Combine the horsepower formula and the specific impulse formula to eliminate the thrust factor.)

••

Mass ratio

Still another method of measuring

rocket performance is by determining the mass ratio. The mass ratio is defined as the ratio of the total mass of the rocket at take-off to the mass of the empty rocket at burnout. Mathematically stated

$$R = \frac{M_p + M_e}{M_e}$$

where R = Mass ratio
M_p = mass of propellant, in pounds
M_e = mass of empty rocket, in pounds

It can be seen from this formula that since the total mass of the rocket at take-off consists of the mass of the empty rocket plus the mass of the propellant, the numerator of the fraction in the formula for R is larger than the denominator. R will, therefore, always be greater than 1. Designers of rockets try to build rockets which have mass ratios on the order of about 6 to 15.

How do scientists design a rocket having a high mass ratio? Let us again look at the formula above. Suppose a rocket is built which when empty weighs 200 lb. and can carry 800 lb. of propellant at take-off. What would be its mass ratio? By substitution in the formula we find that

$$R = \frac{800 + 200}{200} = \frac{1000}{200}$$

$$R = 5$$

Here then the mass ratio is 5. Suppose now that the scientist is able to build a rocket which will weigh only 100 lb. and still be able to carry 800 lb. of propellant at take-off. What will be the mass ratio of this rocket? Again by substitution in the formula we get

$$R = \frac{800 + 100}{100} = \frac{900}{100}$$

$$R = 9$$

Now the mass ratio is 9. Hence, it can be seen that if the rocket can be made lighter but still able to carry the same mass or propellant (in this case 800 lb.), the mass ratio can be increased. Of course there are practical limits to this rule. A rocket must be able to support its own weight as well as the weight of its propellant during take-off and during its burning period. Scientists are today at work trying to find better materials that are able to withstand the tremendous stresses encountered in high speed rocket travel.

Exercises:

D–1. A rocket when empty of propellant weighs 500 lb. It carries 1000 lb. of propellant at take-off. What is the mass ratio?

D–2. A rocket has a mass ratio of 10. The empty rocket weighs 400 lb. How much propellant does it carry at take-off?

D–3. A rocket has a mass ratio of 5. It carries 1000 lb. of propellant at take-off. What is the weight of the empty rocket?

ROCKETRY IN THE FUTURE

At the present time the most common type of rocket engine is the chemical one. However, scientists are busy developing other types. One concept which looks quite promising is the nuclear rocket engine. (see figure 8). In this engine liquid hydrogen is pumped through the nuclear reactor. As a result of the high temperature in the reactor, the liquid hydrogen is changed to a gas. This gas is then passed out through the rocket nozzle where it provides the thrust to propel the rocket.

The ion rocket engine is another type undergoing study. (See Figure 9.) It is propelled by a jet of ions. (Ions are atoms which have either a positive or negative electrical charge on them.) The ions in the engine would be produced by passing a propellant, such as the element cesium or

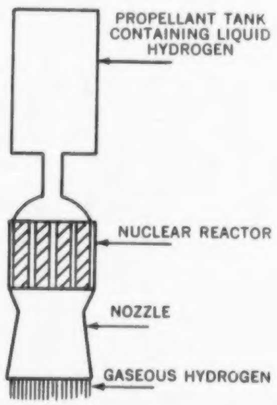


Figure 8. Nuclear rocket engine

rubidium, through an ionizing device, such as a heated grid. The ions would then be accelerated to very high speeds by an electric field after which they would be expelled from the rocket, giving the rocket its thrust.

Still another type is the plasma rocket engine. Plasma is a gas which will conduct an electric current. This gas is made up of neutral particles, free electrons, particles with positive electric charges, and particles with negative electric charges. (NOTE: Do not confuse this plasma with blood plasma. They are entirely different.) In this type of engine a powerful electric arc is passed through a gaseous propellant, forming the plasma, which then passes through the rocket nozzle. The plasma engine is capable of very high specific impulses. Even so it presents a problem to the scientist because it requires a great deal of electrical energy to operate it.

An interesting and, as yet, a speculative kind of rocket engine is the photon engine. In this engine photons, or light particles, would provide the thrust. While such engines would be capable of very high specific impulses, they would require the radiation of intense beams of light. How this amount of radiation could be obtained is not now known. This will be another of many challenges for present and future scientists. How well our scientists are able to meet these challenges will determine our future in space.

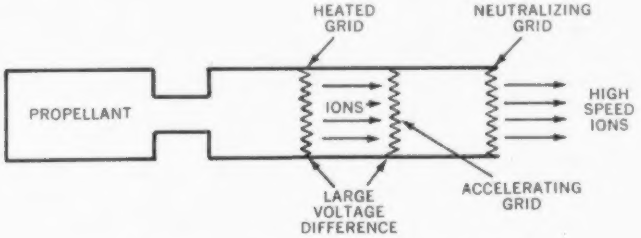
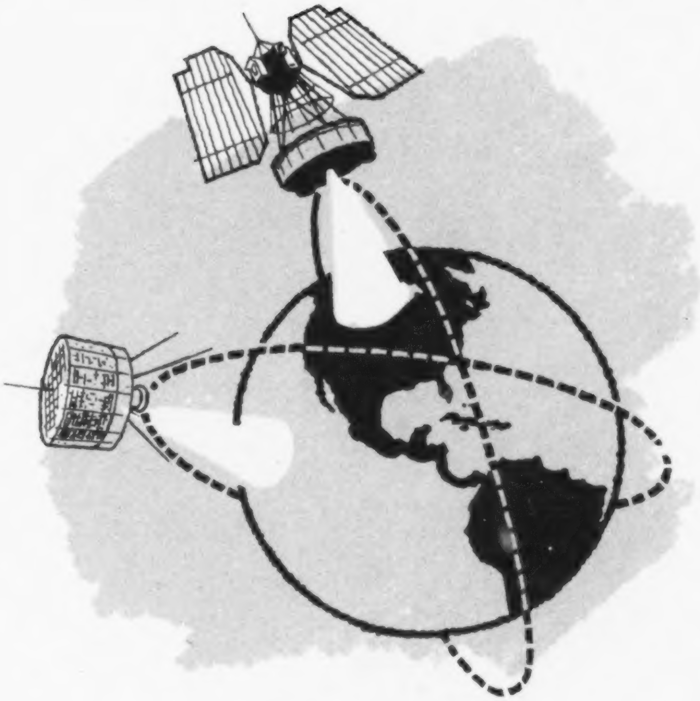


Figure 9. Simplified ion rocket engine



Chapter III

SPACE AND WEATHER

by
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ABOUT THIS CHAPTER

Mathematics is a vital tool of science. Often we do not realize the need to study pure mathematics. In many cases, however, its application proves to be very interesting. When we see how necessary mathematics is to space-science, we begin to realize that without it the exploration of space would be impossible. The activities suggested in this booklet will help you to understand this relationship and to bring space-science into your mathematics classroom.

The distance to the Sun is 93,000,000 miles. Light travels at a speed of 186,000 miles a second. This is 60 × 60 × 186,000 miles an hour. In today's science these are relatively small numbers. In computing we cannot manipulate the numerals which describe the measure of space with ease. Therefore we have devised a shorter way of expressing very long numerals. It is called scientific notation.

SCIENTIFIC NOTATION

We often refer to these very large and very small numbers as macro and micro measurements. This is an area in which it may seem that you are reading a foreign language and you may not have any really good idea of the size (largeness or smallness) of the numbers. For this reason we must understand scientific notation.

Scientific Notation

In scientific notation large and small numbers are written as the product of a number from 1 up to 10 and a power of 10. ($3000 = 3 \times 10^3$).

First we must define some terminology. Let us use as an example $5 \times 5 = 5^2$. In this expression 5 is called the base and the small numeral 2 written to the upper right side of the base is called the exponent. The exponent tells how many times the base is used as a factor and is expressed as the power of the base. We see that

7^3 means 7 is a factor 3 times or
7^3 means $7 \times 7 \times 7$. Thus
10^5 means $10 \times 10 \times 10 \times 10 \times 10$ and
10^5 is read "10 to the fifth power."
We express 10 as 10^1.

……

Problems:

(All the problems are numbered within the text of the booklet. You may check your answers with those given in the back.)

Read each of the following and tell what each means:

(1) 10^2 is read "__________" and means
(2) "__________"
(3) 10^8 is read "__________" and means
(4) "__________"
(5) What is the value of 10^2?
(6) What is the value of 10^8?

……

A more mechanical way of thinking about scientific notation is that the exponent indicates the position of the decimal point. If the exponent is positive, it means that the number is greater than one and that the decimal point must be moved that number of places to the right to give the meaning. In the example 3×10^3 the decimal place has been moved 3 places to the right 3.000. giving 3000. The number 2.15×10^8 would represent $2.15 \times 100{,}000{,}000$. Moving the decimal point 8 places to the right, we have 2.15000000.0 giving 215,000,000.0 Below are more examples:

$$10^2 = 10 \times 10 \text{ or } 100;$$
$$10^3 = 10 \times 10 \times 10 \text{ or } 1000$$
$$2 \times 10^6 = 2 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \text{ or } 2 \times 1{,}000{,}000 \text{ or } 2{,}000{,}000.$$

……

Problems:

(7) What does 8×10^5 mean?

Write the numeral indicated by:

(8) $6 \times 10^3 =$
(9) $5 \times 10^4 =$
(10) $1.5 \times 10^6 =$
(11) $2.5 \times 10^8 =$

Write the following numbers in scientific notation:

(12) 5,000 =
(13) 6½ million =
(14) 30,000 =
(15) 5,500 =

……

If the number is less than one the exponent will be negative. $\frac{1}{10}$ (.1) is written 10^{-1}; $\frac{1}{10 \times 10}$ (.01) as 10^{-2}; $\frac{1}{10 \times 10 \times 10 \times 10}$ (.0001) as 10^{-4} and so on. When the exponent is negative it indicates that the decimal point must be moved to the *left* that number of places. For example $2.15 \times \frac{1}{100}$ ($2.15 \times \frac{1}{10 \times 10}$) would be written as 0.0215 (0.02.15) In the same manner 2.54×10^{-6} would indicate 0.000002.54 (.00000254) In a like manner 0.000000008.02 is written 8.02×10^{-9}. (Remember to count the number of *places* to the right or left of the decimal point, not just the zeros.)

……

For practice with small numbers, complete the following expressions:

(16) 0.00001 = ? × 10 ?

(17) 0.00065 = ? × 10 ?
(18) $6.15 \times 10^{-8} =$
(19) $5.06 \times 10^{-9} =$
(20) $3.45 \times 10^{-6} =$
(21) 0.000001 = ? × 10 ?

For an overall review, complete the following:

(22) 30,000 =
(23) 700 =
(24) 900,000 =
(25) 40 =
(26) $10^{-6} =$
(27) $10^{6} =$
(28) $10^{8} =$
(29) $10^{-8} =$
(30) $2.541 \times 10^{-5} =$
(31) 9,000,000,000,000,000,000 = (incidentaly, this is approximately the number of miles to the galaxy Andromeda, 9 quintillion miles)
(32) $7 \times 10^{7} =$
(33) $8 \times 10^{-8} =$
(34) $3.546 \times 10^{-12} =$
(35) 1 million = ? × 10 ?
(36) 93 million =
(37) 1/10 million = one ten millionth = ? × 10 ?

……

Now you should have enough basics to understand and enjoy this booklet. As you

Table 1.—Conversion Factors

To change the units in column 1 to the units in column 2, multiply by the conversion factor in column 3. These are approxmate values.

Metric to English

From 1	To 2	Factor 3
Millimeters (mm.)	Inches (in.)	.03937
Millimeters (mm.)	Centimeters (cm.)	1/10
Centimeters (cm.)	Inches (in.)	.39
Meters (m.)	Kilometers (km.)	1/1000
Meters (m.)	Inches (in.)	39.37
Meters (m.)	Feet (ft.)	3.28
Kilometers (km.)	English statute miles (mi.)	0.62
Nautical miles	Kilometers (km.)	1.853
Nautical miles	Statute miles	1.15
Cubic inches	Cubic feet	1/1728
Ounces (oz.)	Grams (gm.)	28.35
Kilograms (kg.)	Grams (gm.)	1000
Kilograms (kg.)	Pounds (lbs.)	2.205
Kilograms (kg.)	Liters of H_2O	1
Liters (1.)	Cubic centimeters (cc)	1000
Liters (1.)	Cubic inches (cu. in.)	61
Liters (1.)	Quarts (qt.)	1.05

English to Metric

From 1	To 2	Factor 3
Inches (in.)	Millimeters (mm.)	25.4
Centimeters (cm.)	Millimeters (mm.)	10
Inches (in.)	Centimeters (cm.)	2.54
Kilometers (km.)	Meters (m.)	1000
Inches (in.)	Meters (m.)	1/39.37
Feet (ft.)	Meters (m.)	1/3.28
English statute miles (mi.)	Kilometer (km.)	1.61
Kilometers (km.)	Nautical miles	1/1.853
Statute miles	Nautical miles	1/1.15
Cubic feet	Cubic inches	1728
Grams (gm.)	Ounces (oz.)	1/28.35
Grams (gm.)	Kilograms (kg.)	1/1000
Pounds (lb.)	Kilograms (kg.)	1/2.205
Liters of H_2O	Kilograms (kg.)	1
Cubic centimeters	Liters (1.)	1/1000
Cubic inches (cu. (in.)	Liters (1.)	1/61
Quarts (qt.)	Liters (1.)	.95

(In computing we usually omit the periods on the abbreviations) read it, you will find many conversions, including these. Work each one out to fully understand and to feel the full impact of the sizes of the numbers given here.

CONVERSION FACTORS

When you read scientific papers, you find that the language of scientists different from that used by most of us in our everyday work. For instance, scientists use metric measures such as kilometers (km), millimeters (mm), centimeters (cm), nautical miles, and kilograms (kg) instead of the English units; miles, inches (in), statute miles, and pounds (lb.). You will also find that temperatures, pressures, and other properties are expressed in units not familiar to most of us. As you continue in school and, in life, you will find that these terms keep appearing. If you learn to convert from one system to another, you will find that lectures and papers will mean more to you. When taking science courses, such as physics and chemistry, you will find that you need, not only new science and mathematics, but also a new language.

For these reasons a table of conversion factors has been included for your use. In reading this chapter, you, as a student, should use this table to convert *all* unfamiliar units to units with which you are familiar so that you will have the proper perspective of the concepts and be able to understand them. You probably will have occasional questions. You should answer these questions as you come to them. Check your answers with those given in the back to make sure you understand what is being explained in the chapter.

GENERAL METHODS OF STUDYING THE UPPER ATMOSPHERE

There are three related ways to obtain data for use in studying the upper atmosphere and space as shown in Figure 1 on this page: sounding rockets, satellites, and probes. For our application of mathematics we will consider the first two only.

SOUNDING ROCKETS

Meteorologists have known that atmospheric gases greatly influence the weather on Earth, but for many years they have known very little about the atmosphere surrounding the Earth. Only after the development of rockets and satellites has

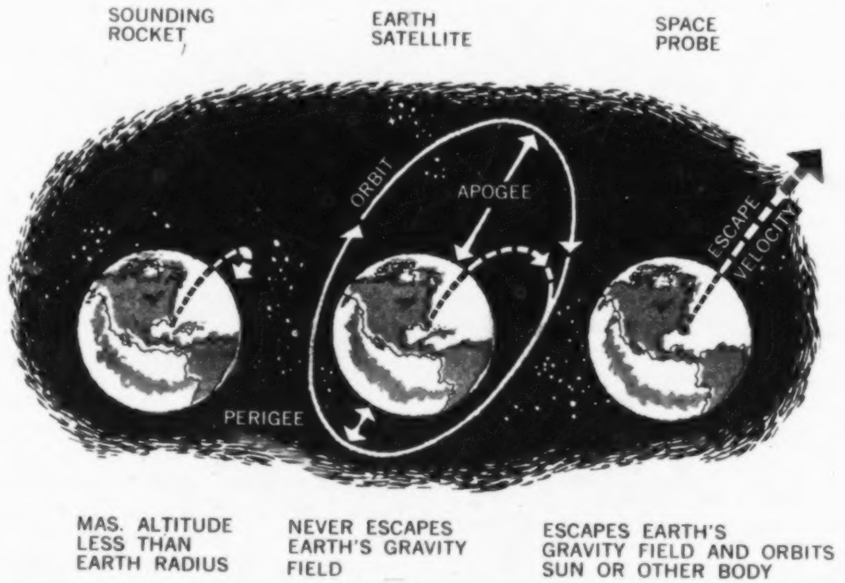
SOUNDING ROCKET
EARTH SATELLITE
SPACE PROBE
ORBIT
APOGEE
ESCAPE VELOCITY
PERIGEE
MAS. ALTITUDE LESS THAN EARTH RADIUS
NEVER ESCAPES EARTH'S GRAVITY FIELD
ESCAPES EARTH'S GRAVITY FIELD AND ORBITS SUN OR OTHER BODY

Figure 1. Some ways to obtain data

more definite information about the atmosphere become available. An important tool for obtaining weather data until the launching of weather satellites was the sounding rocket which is designed to explore the atmosphere within 4,000 miles of the Earth's surface. Most of the rocket probes have been in the 20 to 200 mile region. Multiple staging has enabled rockets to go up to 4,000 miles. With sounding rockets, experiments can be placed in space for a few minutes in a nearly vertical flight profile. The main advantage of sounding rockets is their economy, simplicity, and reliability; but their measurements are limited to specific regions and times.

After World War II several captured German V-2 rockets were used to reach altitudes up to about 120 to 160 kilometers. This is about how many miles? **(38) (This is problem 38.)**

Around 1949 after the captured V-2 rockets were expended, a large number of Aerobee rockets came into use. These rockets produced valuable data on atmospheric pressure, temperature, and density up to altitudes of 100 kilometers (km.). How many miles in altitude is this?**(39)**

A larger rocket named the Viking, similar in size and other respects to the V-2 rockets, but capable of carrying heavy payloads to higher altitudes, was also developed especially for sounding purposes. The Viking could reach an alitude of nearly 300 kilometers (km.). What is this altitude in miles?**(40)** With data from these launchings, several "model atmospheres" were set up by various scientists. Much of the information in figure 2 came from sounding rocket data. In general, before rockets were used, meterologists had to infer the physical properties of the upper atmosphere from ground observations and balloons which rose to 30 kilometers (km.). Rockets gave direct evidence of conditions in the upper atmosphere and the layers of the atmosphere.

ATMOSPHERIC MEASUREMENTS BY ROCKETS

Pressure measurements are made by attaching pressure gauges to certain areas of the rockets known as ambient zones. These are areas on which the pressure remains equal to the atmospheric pressure in spite of the movement of the rocket.

Density of the atmosphere may be measured in two ways. One way is to measure the pressure on the nose of the rocket which depends on the speed of the rocket and on the density of the air. Since the pressure on the nose and the speed is known, the density of the air can be calculated. The second way is by calculating the drag of the atmosphere on a free-falling sphere. This method uses spheres several feet in diameter. A radar beacon attachment is ejected from a rocket at some point in its flight path or trajectory. The sphere is then tracked as it descends and the amount of drag calculated from its rate of descent.

Temperature measurements are difficult to make at high altitudes because of the low density. The best way to make these measurements is by using the local speed of sound. The speed of sound is proportional to the square root of the absolute temperature. Thus, if the speed of sound is known, the temperature can be calculated.

The local sound speed can be found from the pressure distribution on the nose cone of a rocket or it can be determined by ejecting luminescent explosives from a rocket at different intervals of altitude. By noting the time of the flash and the time it takes for the sound to reach the location, the speed of sound is determined.

High altitude winds can be measured by tracking a cloud of glowing sodium vapor released by a rocket at a prescribed altitude. Most of the atmospheric measurements that are used for our more -up-to-date atmospheric structure models have come from sounding rocket data.

ATMOSPHERIC STRUCTURE

It is difficult to show the atmospheric structure in any single picture because great variations occur depending on latitude, altitude, time-of-day, and solar activity. Variations in the upper atmosphere are greater than in the lower atmosphere. The density (number of gas molecules per unit of volume) of the at-

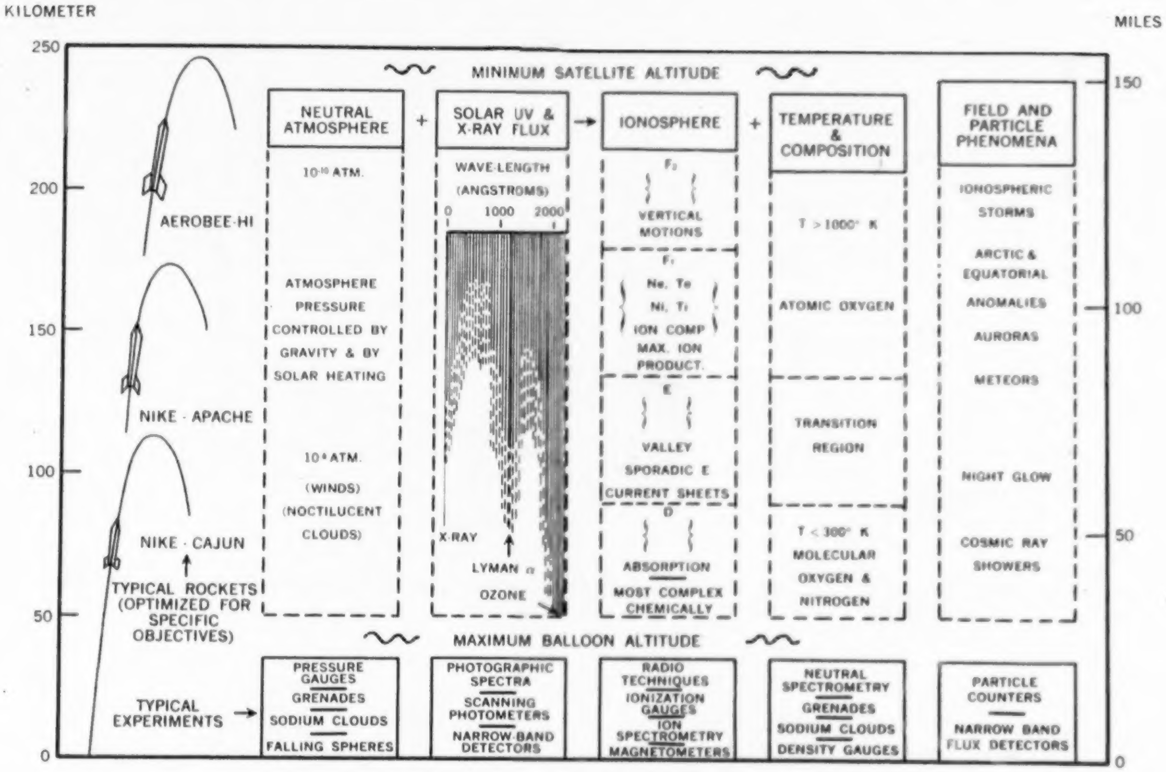
KILOMETER
MILES
250
200
150
100
50
0
150
100
50
0
MINIMUM SATELLITE ALTITUDE
AEROBEE-HI
NIKE · APACHE
NIKE · CAJUN
TYPICAL ROCKETS (OPTIMIZED FOR SPECIFIC OBJECTIVES)
NEUTRAL ATMOSPHERE
+
SOLAR UV & X-RAY FLUX
IONOSPHERE
+
TEMPERATURE & COMPOSITION
FIELD AND PARTICLE PHENOMENA
10⁻¹⁰ ATM.
ATMOSPHERE PRESSURE CONTROLLED BY GRAVITY & BY SOLAR HEATING
10⁻⁴ ATM.
(WINDS)
(NOCTILUCENT CLOUDS)
WAVE-LENGTH (ANGSTROMS)
0 1000 2000
X-RAY
LYMAN α
OZONE
F₂
VERTICAL MOTIONS
F₁
Ne, Te
Ni, Ti
ION COMP
MAX. ION PRODUCT.
E
VALLEY
SPORADIC E
CURRENT SHEETS
D
ABSORPTION
MOST COMPLEX CHEMICALLY
T > 1000° K
ATOMIC OXYGEN
TRANSITION REGION
T < 300° K
MOLECULAR OXYGEN & NITROGEN
IONOSPHERIC STORMS
ARCTIC & EQUATORIAL
ANOMALIES
AURORAS
METEORS
NIGHT GLOW
COSMIC RAY SHOWERS
MAXIMUM BALLOON ALTITUDE
TYPICAL EXPERIMENTS
PRESSURE GAUGES
GRENADES
SODIUM CLOUDS
FALLING SPHERES
PHOTOGRAPHIC SPECTRA
SCANNING PHOTOMETERS
NARROW-BAND DETECTORS
RADIO TECHNIQUES
IONIZATION GAUGES
ION SPECTROMETRY
MAGNETOMETERS
NEUTRAL SPECTROMETRY
GRENADES
SODIUM CLOUDS
DENSITY GAUGES
PARTICLE COUNTERS
NARROW BAND FLUX DETECTORS

Figure 2. Basic research requiring low altitude sounding rockets

mosphere decreases as the distance from the Earth increases; except for ozone, which reaches its maximum at 20 to 30 miles because of the ultraviolet action of the sun's rays. This variation is known as an inverse proportion or inverse variation, meaning that as one value increases, the other decreases. Beyond 200 miles, the major constituents of the atmosphere of space consist of atomic oxygen, of atomic helium (He) at about 700 miles, and of atmoic hydrogen at 2000 miles and beyond.

....

Problems:

The Earth's atmosphere on the average exerts a pressure of 760 millimeters of mercury (760 mm of Hg) at sea level. What would this pressure be in inches of mercury?**(41)** This pressure is known as a standard atmosphere (atm). Pressure decreases roughly by a factor of 10 for each 10-mile increase in altitude up to 60 miles. How would this altitude be shown in Figure 3?**(42)** At 100 miles the pressure is about how much in atmospheres?**(43)** How would this be expressed in millimeters (mm.) and inches (in.)?**(44)** These figures show that all but one-one billionth of the Earth's atmospheres lies below 100 miles. The pressure for the next 100 miles again changes by a factor of 10. At 500 miles it is about 10^{-9} millimeters of mercury (mm Hg); at 1,000 miles about 10^{-10} (mm Hg). How would these pressures be written in inches (in.)?**(45)** The pressure in solar space is estimated to be between 0.000000000001 and 0.00000000000001 mm. Hg. How would this be written in scientific notation? **(46 & 47).**

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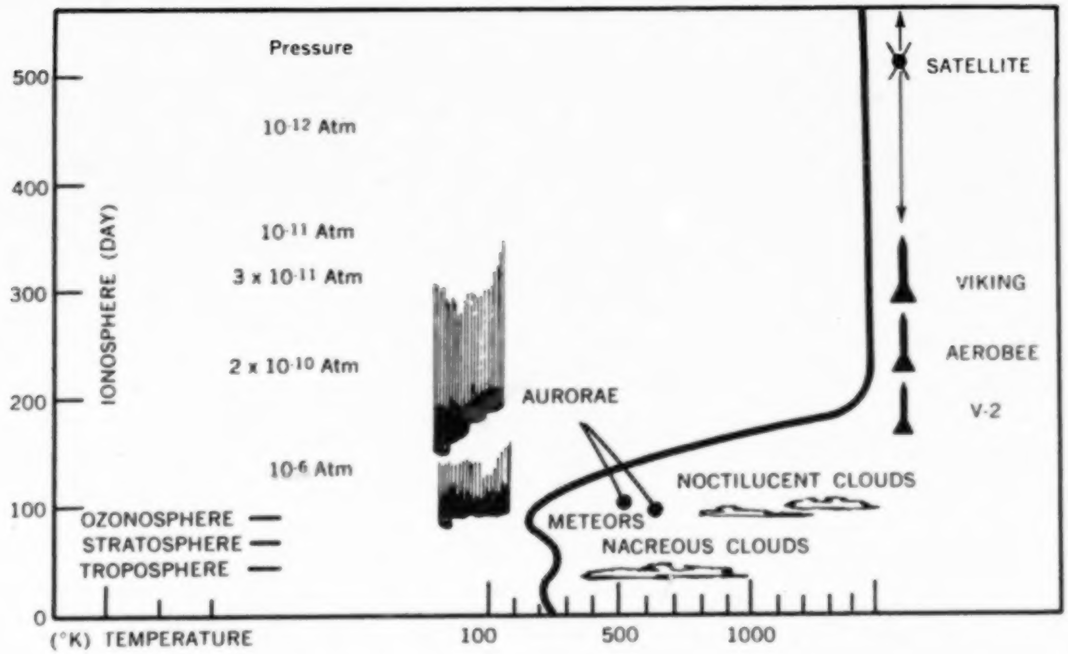


Figure 3.

As mentioned earlier, most of the more modern data on the atmospheric structure comes from sounding rockets. The properties of the atmosphere had been measured very accurately up to altitudes of 100 kilometers (km.) and less accurately from 100 to 200 kilometers (km.). Above this point, all information was based on extrapolations or educated guesses based on data from the lower altitudes, and assuming that the trends continue into the upper atmosphere.

……

Problems:

Referring to figure 3, answer the following questions:

(48) How many miles would 100 kilometers (km.) be?

(49) How many miles would 150 kilometers (km.) be?

(50) How many miles would 200 kilometers (km.) be?

(51) How many miles would 300 kilometers (km.) be?

(52) How many miles would 600 kilometers (km.) be?

(53) What is the atmospheric pressure at 100 km? In atmospheres? In millimeters (mm.)?

(54) How many inches of mercury would be shown on a barometer at 100 kilometers (km.)?

(55) Write out the pressure at 500 kilometers (km.) in atmospheres without using scientific notation.

(56) Write out the pressure at 200 kilometers (km.) as it would be without scientific notation.

……

As you may have noticed by now, the temperature scale at the bottom of the diagram or graph of the conditions of the atmosphere is divided into °K. K stands for Kelvin or absolute temperature. You probably have heard that as the temperature is lowered, a gas decreases in volume and pressure. Theoretically, the temperature might reach a point where the gas would have essentially disappeared with no volume and no pressure. This temperature is known as absolute zero or zero degrees Kelvin for one of the originators of the idea. So degrees Kelvin (°K) is absolute temperature.

Now, if you are not thoroughly confused already, remember that we have two other temperature scales as well (centigrade or Celsius, °C and Fahrenheit, °F). This creates a slight problem in conversion with which you will become familiar. There is no difference in the size of a degree on the Celsius and absolute scales. This means that there are the same number of degrees, for instance, between the freezing point and the boiling point of water on both scales. 273° on the absolute scale is equal to 0° on the Celsius scale, so to convert from °K to °C, simply subtract 273°. To convert °C to °K, add 273°.

However, there is a difference in the *size* of a degree between the Celsius scale and the Fahrenheit scale. To be more exact, 5° on the Celsius scale is equal to 9° on the Fahrenheit scale. This ratio accounts for the older formulae for conversion of temperatures. However, recently someone noticed that the Fahrenheit and Celsius scales are the same at −40 degrees and derived two new and simpler formulae. With a little study on your part, you, too, should be able to understand how these formulae were formulated.

These formulas are as follows:

$$C = \frac{(F^\circ + 40^\circ)}{1.8} - 40^\circ$$

$$F = [(C^\circ + 40^\circ)\ 1.8] - 40^\circ$$

Remember, begin work by performing the operation indicated inside the parenthesis and finish by subtracting 40. If the problem is not worked in the proper order, the correct answers cannot be obtained. Study the examples below:

Change 32°F to Celsius

$$C = \frac{(F^\circ + 40^\circ)}{1.8} - 40^\circ$$

$$C = \frac{(32^\circ + 40^\circ)}{1.8} - 40^\circ = \frac{72^\circ}{1.8} - 40^\circ =$$

$$C = 0^\circ \qquad 40^\circ - 40^\circ = 0^\circ$$

Working the opposite way, change 0°C to Fahrenheit temperature.

$$F = [(C^\circ + 40^\circ)\ 1.8] - 40^\circ$$

$$F = [(0^\circ + 40^\circ)\ 1.8] - 40^\circ$$

$$F = [(40^\circ)\ 1.8] - 40^\circ$$

$$F = 72^\circ.0 - 40^\circ$$

$$F = 32^\circ$$

……

Problems:

Now, using these formulae and procedures, answer the following questions from figure 3.

(57) What is the temperature at 25 km. in Celsius degrees?
(58) What is this temperature in Fahrenheit degrees?
(59) What is the temperature at 50 km. on the Celsius scale?
(60) What is the reading on the Fahrenheit scale?
(61) What is the temperature at 100 km. on the Celsius scale?
(62) What is the reading on the Fahrenheit scale?
(63) What is the temperature in °C at 200 km?
(64) What is the temperature in °F?
(65) What is the temperature in °C at 500 km?
(66) What is the temperature in °F?

……

Because much outer space information is based on extrapolation, one of the first jobs assigned to the satellites was to measure the properties of the upper atmosphere. It was assumed that the satellite information would follow the extrapolated information fairly closely. However, the actual data yielded many unexpected discoveries, such as great variations in the density of the upper atmosphere, some of which change from day to day and are connected with the activity of the sun.

Because of the findings of the early satellites, other satellites have been planned to further increase our knowledge of the atmospheric structures. One of these, the Atmospheric Structures Satellites, were developed to measure density, composition, neutral particle temperature, and electron temperatures of the atmosphere out to 400 nautical miles. How many statute miles would this be?**(67)**

It is thought that these variations and conditions farther out influence our weather conditions on earth.

Another type of satellite used in atmospheric studies is the TIROS (*T*elevision

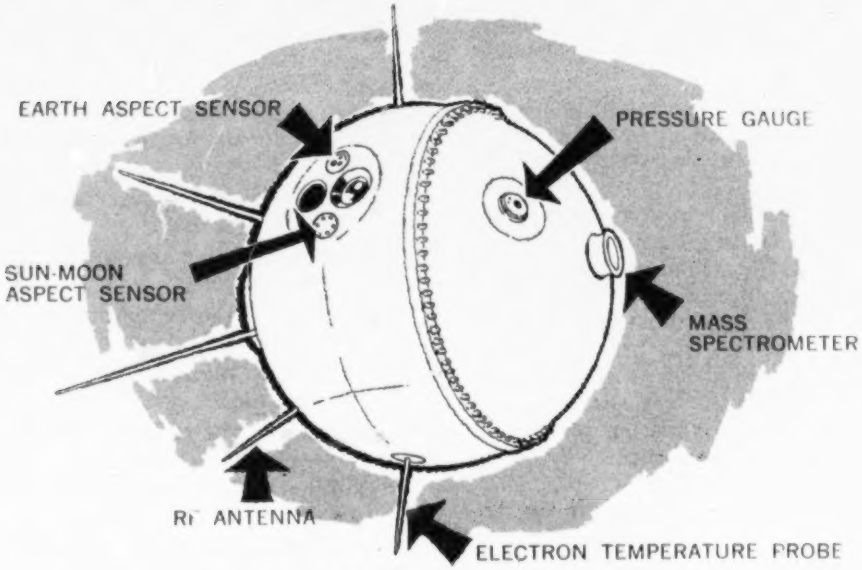


Figure 4. Atmospheric structures satellite

*I*nfra-*R*ed *O*bservation *S*atellite) series. Infra-red equipment is used to provide information on how the sun's energy is absorbed and reflected by the Earth's atmosphere. TIROS also has another important mission, which is of immediate use—that of observing the cloud cover and the movement of storms. Information from TIROS is used immediately by the United States Weather Bureau for weather analyses. Information now being obtained by TIROS aids greatly in weather forecasting throughout the world.

Although TIROS is usually shown as being shaped like a bass drum, it is actually a regular polygon with 18 sides. In regular polygon all the sides are equal in length, and all the angles are equal. If you would like to see this strangley shaped satellite, try drawing it yourself. The procedure is very simple. The only equipment needed are a pencil, a compass, a ruler, and a protractor. The diameter of TIROS is 42 inches from the center of one flat side to the center of the opposite flat side. A good scale for this project would be 1:8. This ratio indicates that one unit on the paper represents 8 actual units. How many inches in your drawing represent the 42 inch diameter of the satellite?**(68)** What is the length of the radius of the satellite on this scale?**(69)**

CONSTRUCTION OF THE BASE OF TIROS

1. Using this length, set the points of the compass on the radius.
2. Draw a circle lightly as shown in figure 5 slightly larger than the diameter of the TIROS satellite using the scale of 1:8.
3. Divide the circle into 18 equal angles. How large would each angle be?**(70)** (*see figure 5*).
4. Using the center of the circle as the center, draw an arc (CD) in each of the angles.
5. With C as a center and any radius, draw an arc as the arc at E.
6. Then with D as a center and with the *same* radius, draw another arc intersecting the first one at E.
7. Draw the bisector of the angle from the center of the circle through E, the scale length of the radius of TIROS.
8. Draw a line perpendicular to the bisector forming the base of the triangle and one of the eighteen sides of the base of TIROS.
9. Use this procedure on each of the triangles and you will have a scale drawing of the base plate of TIROS.

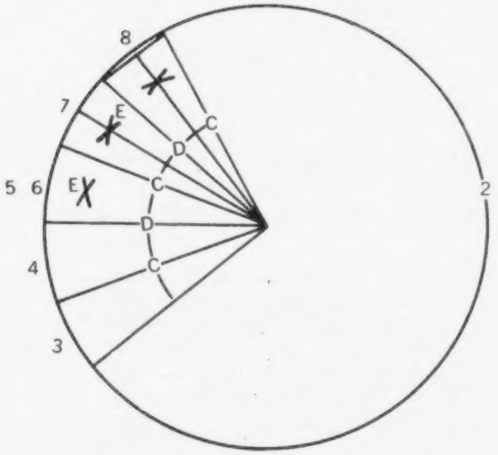


Figure 5.

Problems:

As you can see from the scale drawing of TIROS, it is nearly circular in cross-section. Because it is so nearly circular, the volume of TIROS can be approximated by using the formula for the volume of a cylinder. Volume = $\pi r^2 h$ where r = radius, h = height and approximate $\pi = 3.14$. The diameter of TIROS is 42 inches and the height of TIROS V is 19 inches. What is the approximate volume of the TIROS weather satellite in cubic inches (cu. in.) ?**(71)** If you computed the volume, you found that it is a little more than 26,300 cubic inches (cu. in.). If you check into a set of reference tables, you will find that there are 1,728 cubic inches (cu. in.) in one cubic foot (cu. ft.). Divide your previous answer in cubic inches (cu. in.) by 1,728, to get the volume in cubic foot (cu. ft.).

How many cubic feet (cu. ft.) of space are there in TIROS V ?**(72)** TIROS VIII is again 42 inches in diameter, but is $22\frac{1}{2}$ inches high, instead of 19 inches high. What is the volume of TIROS VIII in cubic feet (cu. ft.) ?**(73)**

For a more exact measurement you can, if you wish, use trigonometry and come closer to the volume measurements used by NASA. Remember that inside this 18 sided polygon, there can be constructed 18 congruent isosceles triangles using each flat side as a base. Each isosceles triangle is bisected by a perpendicular (the radius) from the center of the polygon to the center of the base forming two right triangles. Remember that the angle at the apex of each isosceles triangle will be equal to $\frac{1}{18}$th of 360°. By using the tangent of $\frac{1}{2}$ this angle (opp./adj.) and the previous given information, the length of $\frac{1}{2}$ the base of the isosceles triangle can be determined. Once you have the base, use the formula for the area of the triangle $\left(A = \frac{1}{2} bh\right)$ and figure the area of each isosceles triangle. Multiply this area by 18 to get the area of the base plate of TIROS satellites. Now multiply this area by the height of the satellite to get the volume of a TIROS satellite.**(74)**

THE TIROS PACKAGE

The electronics package of a TIROS satellite is composed chiefly of the following equipment: FM television transmitters, power supply and regulator, beacon transmitters, horizon sensor and associated circuitry, command receivers, clock and control circuitry, telemetry sensors, north indicator and associated circuitry, infrared sensors and package (amplifiers, FM sub-carrier oscillators, tape recorders, and FM transmitters), two TV cameras, tape recorders, and magnetic attitude control circuitry. TIROS VIII had all of these items, as well as additional equipment for automatic picture transmission (APT) which made it possible for ground stations throughout the world to receive weather data as the satellite orbited overhead.

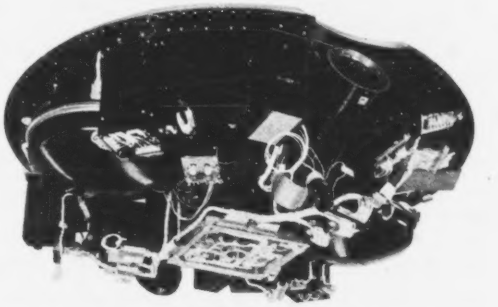


Figure 6. Photograph of TIROS base plate

Many of the components are mounted on the base plate of the satellite. Because so much has to be included in a relatively small space, all of the equipment must be miniaturized or made smaller to take up less space. To give an idea as what is meant here, a section of a computer approximately six to eight inches long, three to four inches wide, and at least one and one-half inches thick has been reduced to the size of a shirt button and does the same job. A television camera for TIROS may be a tube one inch in diameter and four to six inches long.

LAUNCHING OF SATELLITES

So far, we have discussed the size and shape of the TIROS satellites and very briefly two of their uses. Before anything more can be said about the orbits and the observations of the TIROS series, we have to get TIROS off the ground and into orbit around the Earth.

TIROS has been launched by the Delta booster or launch vehicle which is approximately 90 feet (ft.) high (actually 88 feet without the spacecraft) and 8.1 feet (ft.) in diameter with a weight of 57 tons. It was originally intended to be used to launch medium payload satellites and space probes until newer vehicles could become operational. However, the Delta has been so successful that it has proven to be one of the most reliable launch vehicles possessed by the United States. The vehicle uses a modified Thor booster as its first stage which is a 57 foot, liquid-fueled rocket which generates approximately 170,000 pounds of thrust in a burning time of two minutes and 25 seconds. Thrust is hard to visualize, so let us try to express this thrust in horsepower (HP).

Now anyone who knows physics would say that we cannot equate thrust and horsepower (HP) unless the velocity is specified. This is because the definition of one horsepower (HP) is that one horsepower (HP) is equal to the force required to raise 33,000 pounds (lb.) at the rate of one foot per minute (1 HP = 33,000 ft. lb./minute). Roughly, though, it has been estimated that it takes about 22 horsepower (hp.) to develop one pound (lb.) of thrust at average launch conditions.

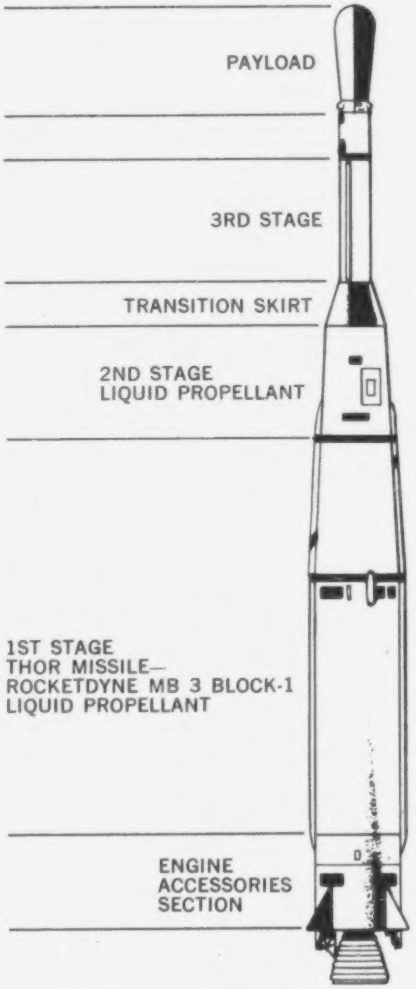


Figure 7. Delta launch vehicle

If you use this figure, how many horsepower could be developed by a first stage of the Delta Launch vehicle?**(75)**

The second stage of the Delta launch vehicle is an improved second stage from the Vanguard and Thor-Able programs, as was the first stage. It develops about 7,500 pounds (lb.) of thrust for 160 seconds. How many horsepower (HP) are developed by the second stage?**(76)**

The third stage is the Altair, which is a solid propellant booster also from the Thor-Able and Vanguard vehicles. As you can see, the Delta has taken proven engines and modified them for better reliability and newer missions. This stage produces 3,000 pounds (lb.) of thrust for 10 seconds to complete the launch.

……

Problems:

How many horsepower are produced by the Altair booster?**(77)** Now counting six minutes of coasting after the burnout of the second stage, how many minutes and seconds does the launching of TIROS require?**(78)** Does the successful launching require more than an hour or less than an hour?**(79)**

……

It might be interesting to make a scale model of the Delta launch vehicle using the data given here as to height and diameter. Materials required for this activity would be a pair of scissors, a ruler, and some wrapping paper. Use a scale of ¼ inch = 1 foot for a large representation, and shape the paper to resemble the actual vehicle.

ORBITS OF SATELLITES

The path of the satellite around the Earth is known as its orbit. It is placed in orbit with a speed and direction (velocity) which causes it to "fall" continually around the Earth. Everything sent into the outer reaches of our atmosphere at speeds under 18,000 miles per hour or five miles per second falls back to the Earth.

As you probably know, a falling body falls 16 feet the first second. Our satellite also falls 16 feet in the first second; but as it falls 16 feet, it has traveled five miles horizontally, which happens to be equal to the curvature of the earth—16 feet in five miles. Thus, the satellite is still just about as far from the surface of the Earth as it was in the beginning, so we say it is falling around the Earth and will continue in this manner until air drag slows or pulls it down.

This can be explained in another way by using Newton's First Law that says "A body in motion tends to remain in motion *in the same straight line* unless acted upon by some unbalanced force." This resistance to a change of velocity is called "inertia". The satellite "tries" to continue in a straight line except for the unbalanced force, in this case, gravity, which moves it into a curved path around the Earth. The directed speed or velocity needed to place an object into an orbit is known as orbit velocity.

If the satellite is moving at the right velocity, its centrifugal force (a form of inertia) and the force of the Earth's gravity will be in equilibrium, or just about balanced, causing it to follow a circular orbit about the Earth. This is the hardest orbit to obtain because the *exact* speed is extremely hard to produce.

Most natural objects follow elliptical orbits or forms of an ellipse. The ellipse looks like an elongated circle and is much easier to attain than a circular orbit. It is a closed curve in which the sum of the distances from any point on the curve to two internal points, called the foci, is always constant (the same). The point of the ellipse or eliptical orbit, as shown in figure 1, nearest the surface of the Earth is called perigee (*peri* meaning near and *gee* from *geo* meaning Earth). The point farthest from the Earth in figure 1 is called apogee.

The orbits of our Earth satellites are named according to their relationships to the surface of the Earth; for instance, a polar orbit passes over both poles. An equatorial orbit is over only the equator. An orbit between polar and equatorial orbit is called an inclined orbit and is described by using the angle it makes with the equator.

The TIROS satellites are in nearly circular, inclined orbits. The earlier satellites were inclined 48° to the equator; however, the inclination was increased to 58° in order to view areas nearer to the polar region where much of our weather originates. Also, the higher inclination benefited the study of sea ice. One disadvantage of this orbit is that the areas covered extend only from 60° N to 60° S so that nothing in close proximity to the polar regions could be observed. Scientists are now planning near polar orbits for future TIROS missions. The orbital altitude of TIROS is about 380 nautical miles; how many statute miles is this? (Use your conversion factors!)**(80)** A main disadvantage of TIROS is that it is space oriented.

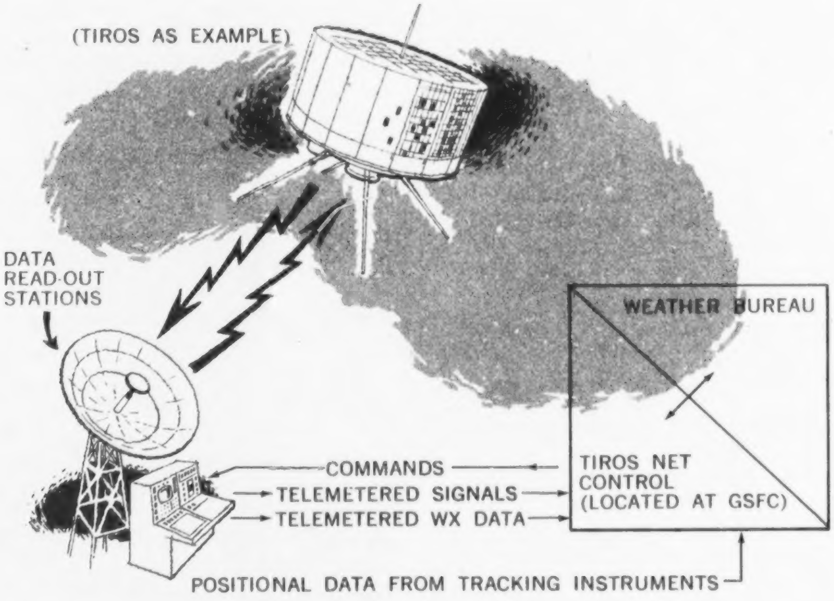

(TIROS AS EXAMPLE)
DATA READ-OUT STATIONS
WEATHER BUREAU
TIROS NET CONTROL (LOCATED AT GSFC)
COMMANDS
TELEMETERED SIGNALS
TELEMETERED WX DATA
POSITIONAL DATA FROM TRACKING INSTRUMENTS

Figure 8a.

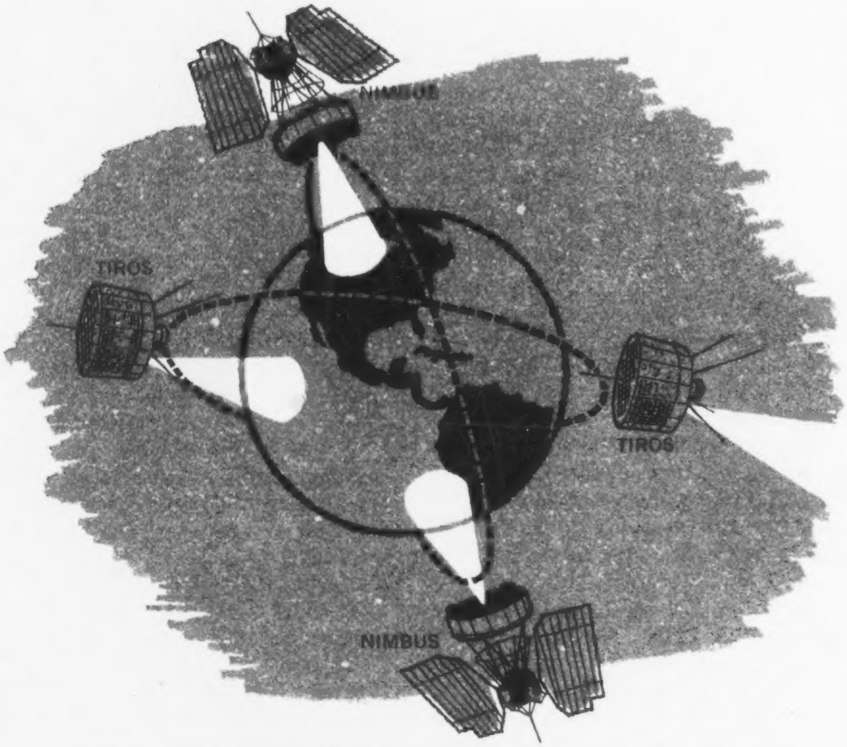

NIMBUS
TIROS
TIROS
NIMBUS

Figure 8b. Orientation of Nimbus and TIROS satellites

This means that the axis of TIROS is constantly pointed in a fixed direction in space. In Figure 8b, TIROS faces the Earth only through 1/3 of its orbit. Even though pictures can be taken only in daylight, 10 to 25 percent of the Earth is covered by TIROS.

While the TIROS weather satellites were being developed they provided much valuable data which aided meteorologists in forecasting hurricanes, typhoons, ice melts and other weather phenomena. Already these satellites helped save an untold number of lives and property damage. After 5 years of experimental flights TIROS will become the world's first operational meteorological satellite.

WHAT NEXT?

The next "generation" weather satellite, is Nimbus first launched in the summer of 1964. It is much larger than TIROS. Nimbus stands 10 feet high and, with the solar paddles extended, is 13 feet (ft.) wide. It weighs 650 pounds (lb.), which is more than twice as heavy as TIROS. The first Nimbus satellite was placed in an orbit about 600 nautical miles above the earth. What would this altitude be in statute miles. **(81)**

Nimbus takes advantage of many advances made possible by TIROS. First it keeps its cameras facing the earth at all times, thanks to a unique horizon sensing system. It is placed in a polar orbit, thus giving coverage of clouds over every portion of the earth each 24 hours. Finally, it transmits photographs continuously to inexpensive ground stations anywhere in the world.

The base section of the spacecraft contains all camera and radiation-sensing equipment and other experiments. The upper section contains power and stabilization systems. Its two solar cell paddles are pointed continuously toward the sun.

Its camera system consisted of:

Three Advanced Vidicon Camera Systems (AVCS) which produce an 800 scan line one-half mile resolution picture.

One Automatic Picture Transmission (APT) system which sends instant photos

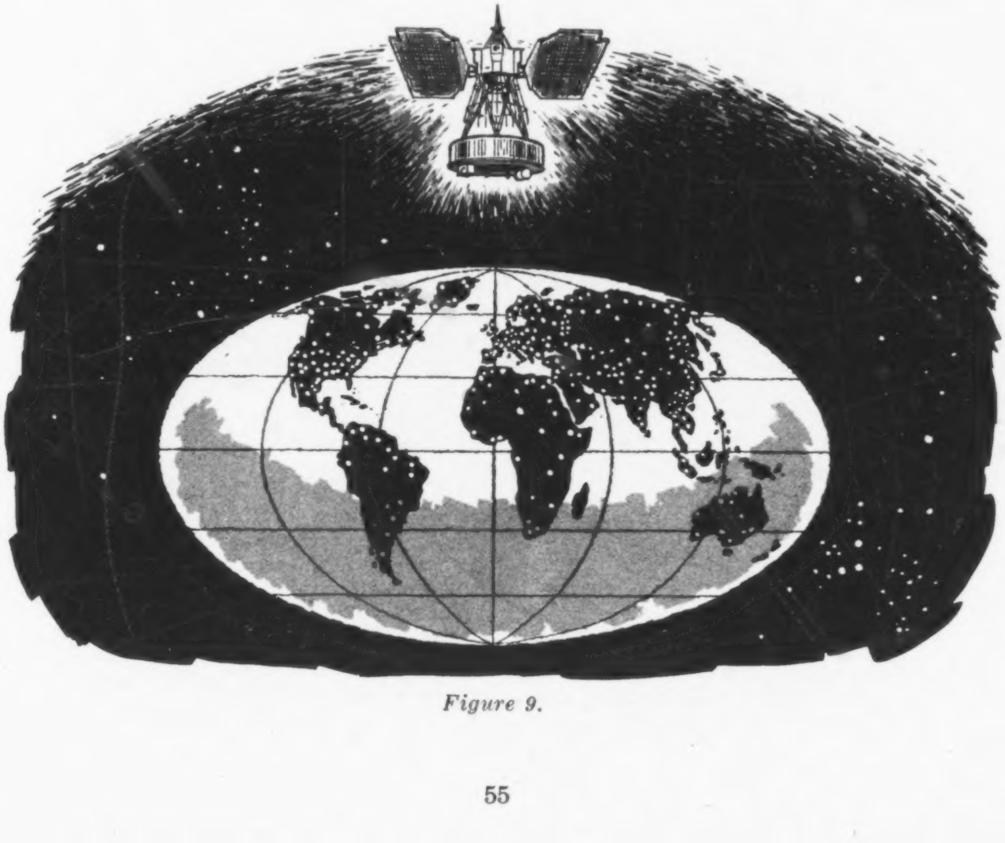
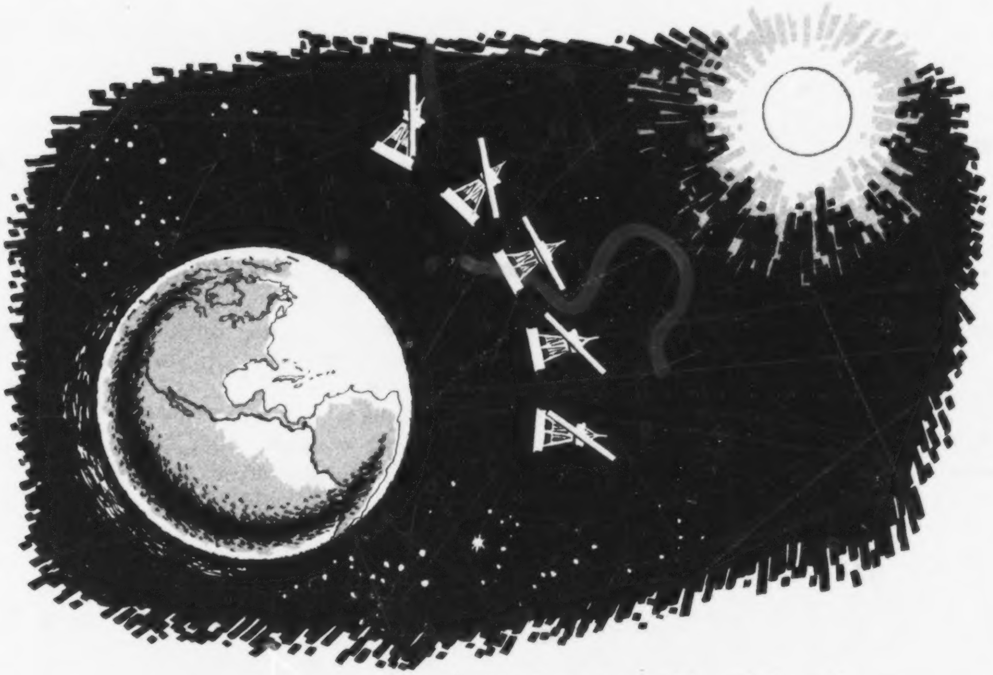
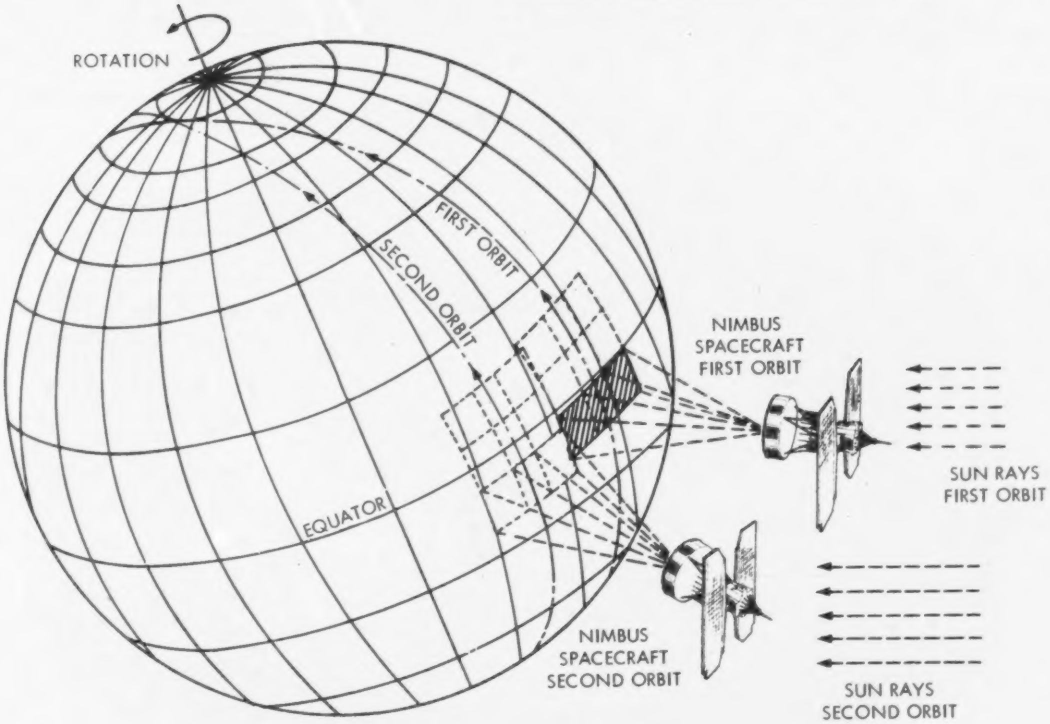


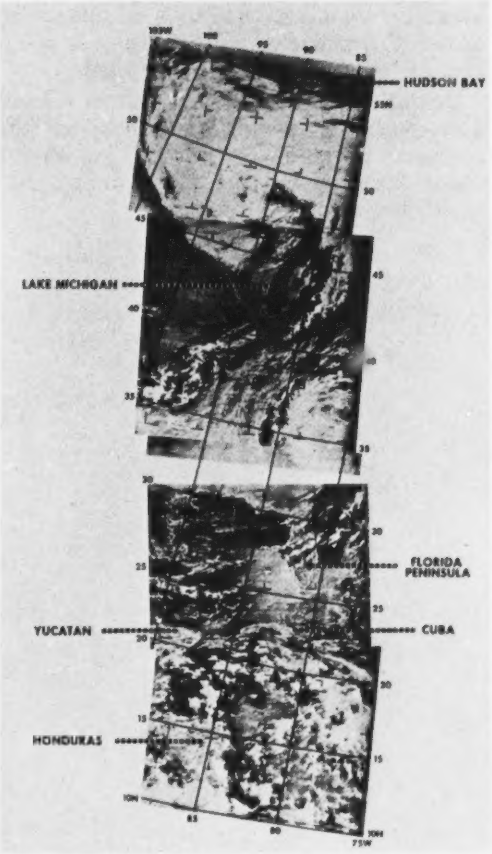
Figure 9.



Nimbus solar paddles "follow" the sun


ROTATION
FIRST ORBIT
SECOND ORBIT
NIMBUS
SPACECRAFT
FIRST ORBIT
SUN RAYS
FIRST ORBIT
EQUATOR
NIMBUS
SPACECRAFT
SECOND ORBIT
SUN RAYS
SECOND ORBIT

How Nimbus photographs the world's weather



Nimbus looks at the Earth

to relatively inexpensive ground stations located around the world. APT uses the slow scan television technique similar to that used in radio facsimile transmission and has a resolution of some 3 miles.

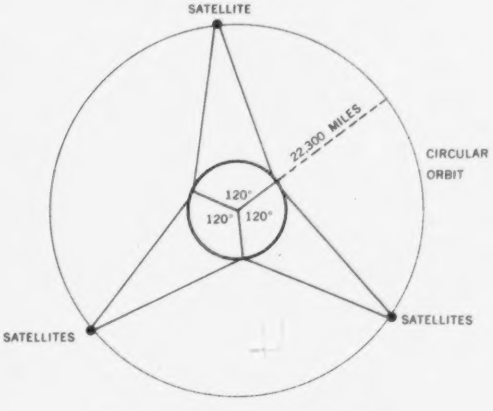
One High Resolution Infrared Radiometer (HRIR) system which measures heat in the Earth and clouds and produces nighttime photographs. It has a resolution of approximately 4 miles.

Polar orbit and the Earth's rotation enable these systems to transmit more than 2,000 photographs per day. Nimbus covers the entire world in fourteen orbits or once daily.

Two Data Acquisition Facilities one at Rosman, North Carolina and the other at Gilmore Creek, Alaska receive all spacecraft performance telemetry data and meteorological data via their 85-foot parabolic antennas. These data are microwaved to the Goddard Space Flight Center in Greenbelt, Maryland. Meteorological data are then sent to the U. S. Weather Bureau in Suitland, Maryland. The Nimbus Technical Control Center at Goddard evaluates all spacecraft performance and determines command instructions to be sent to the satellite by the Rosman and Gilmore Creek Stations.

From studies of the duration and sizes of various types of storms, it has been found that using one or two weather satellites most hurricanes and larger storms could be observed.

For a more continuous observation system, a Synchronous Meteorological Satellite system is being investigated. This type of spacecraft might be placed in an equatorial orbit at an altitude of 22,300 miles. At this altitude the satellite would appear stationary, because it would revolve around the Earth at the same rate that the Earth rotates. A satellite of this type could observe about one-third of the Earth at one time with its cameras as shown in figure 9. Thus three satellites could give continuous observation of the entire globe.



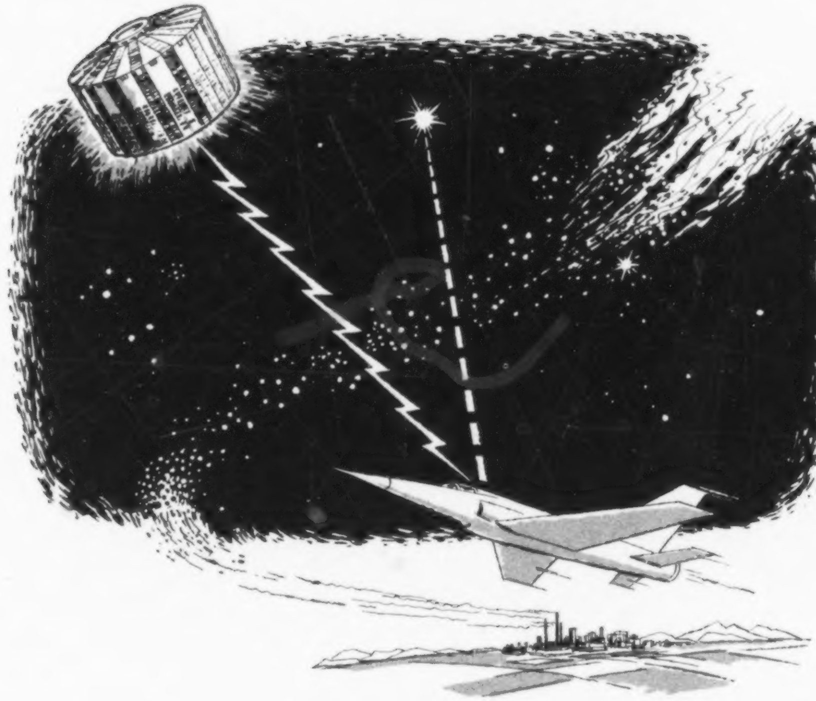
The 24-hour satellite system

CONCLUSION

We could go on indefinitely because the study of the atmosphere is continuous. New methods are constantly being developed; even at this time, a new type of

TIROS satellite is being readied for launching, which, once in orbit, will turn on its side and roll through space like a wheel. Much more is on the drawing boards and in men's minds. Some day the generation that is in the schools of today will be putting their ideas and imaginations to work. Instead of studying the weather, we might be able to do something about it. Instead of warning people about storms, we will be destroying them.

Scientists and engineers using science and mathematics will help produce the answers in man's quest for knowledge about himself and the environment into which he was born.



Chapter IV

SPACE NAVIGATION

by
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ABOUT THIS CHAPTER

Navigation now includes outer space as well as the earth and its atmosphere. Measurement is a necessary part of navigation and a good mathematical background is essential if we are to understand the complexities of our space age.

This chapter has been developed to help you to actually experience some of the ways in which mathematics are used to travel through space where there are no familiar landmarks or road signs. Therefore, the more you know of mathematics, the better you will be able to "navigate" through the exercises. Should you find that you need to know some math you have not taken—look it up!

Figure 1.

MAPS FOR NAVIGATION

A navigator must know how to locate his position by recognizing objects on the ground which he can see from his position in the air. To help him do this the United States Department of Commerce Coast and Geodetic Survey compiles and prints maps called Sectional Aeronautical Charts which include prominent land marks marked in a code which is understood by a navigator. See Figure 2. These maps have a scale of 1:500,000. This means that 1 inch on the chart represents 500,000 inches on the Earth's surface.

……

Problems:

1. To the nearest mile, approximately how many miles would 500,000 inches represent?
2. If you are to travel between two cities which are represented by a distance of 2½ inches between them on the chart, how far is the distance actually in miles between the cities?
3. According to your map, what is the air mileage between the Benedum airport near Bridgeport, West Virginia and the Morgantown airport at Morgantown, West Virginia. The small circles are the symbols used to denote airports. (See figure 2.)
4. What is the distance between the Connellsville, Pennsylvania, airport and the Green County, Pennsylvania airport? (See figure 2.)

……

A navigator must know how to measure distances accurately from his charts and also know which way to turn in the vast ocean of space to reach his destination. If he examines his chart closely he will notice that there are two sets of lines, one set of clearly marked horizontal lines (lines of latitude) and one set of vertical lines (lines of longitude). The lines of longitude all terminate at the geographic north pole and the geographic south pole. They give the direction of geographic, or what is sometimes called "True", north.

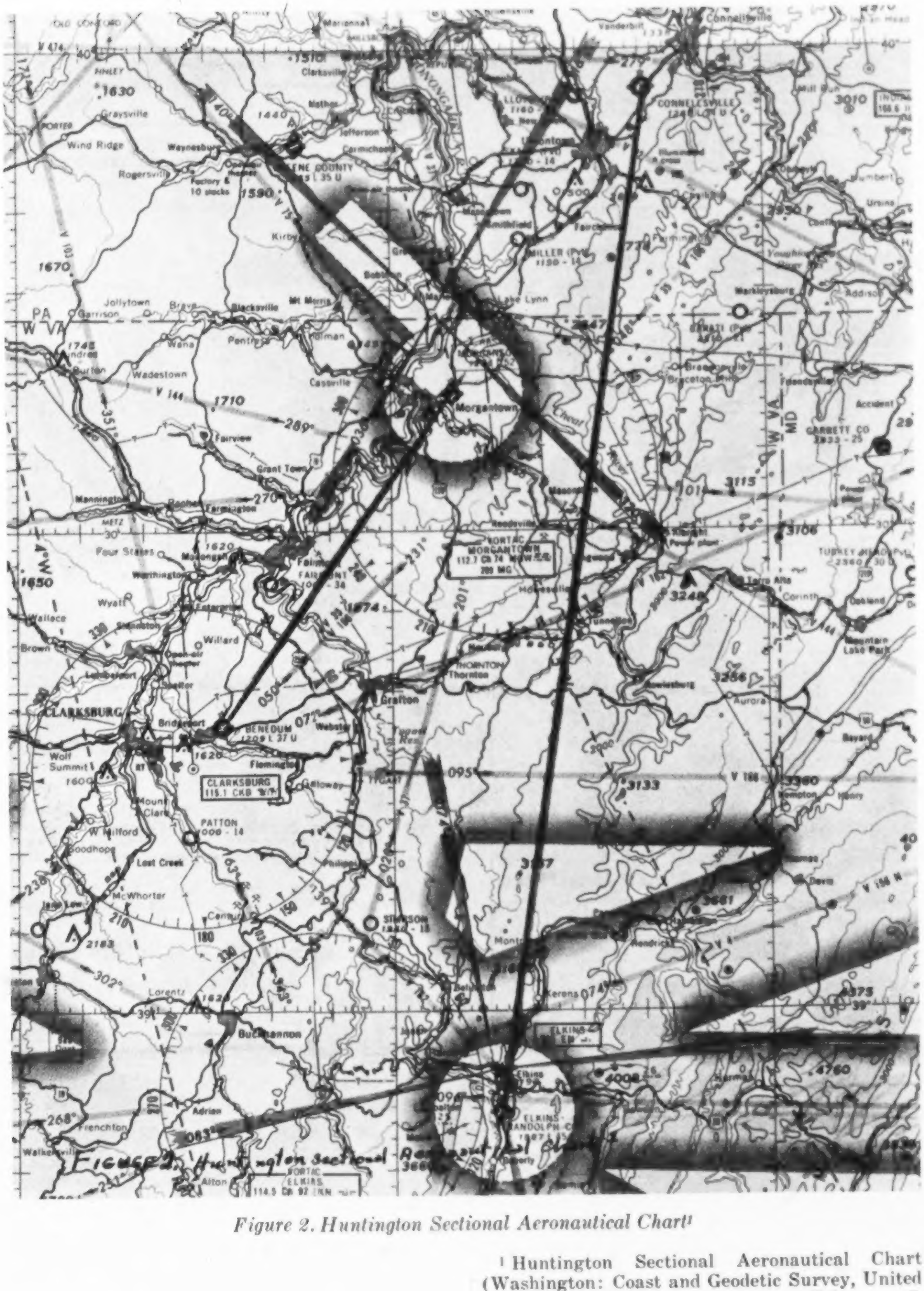
Connellsville
Waynesburg
Morgantown
MORGANTOWN
Fairmont
Clarksburg
CLARKSBURG
BENEDUM
Bridgeport
Grafton
Buckhannon
Elkins
ELKINS-RANDOLPH CO
PA
W VA
MD
Figure 2. Huntington Sectional Aeronautical Chart

Figure 2. Huntington Sectional Aeronautical Chart[1]

[1] Huntington Sectional Aeronautical Chart (Washington: Coast and Geodetic Survey, United States Department of Commerce, February 6, 1964).

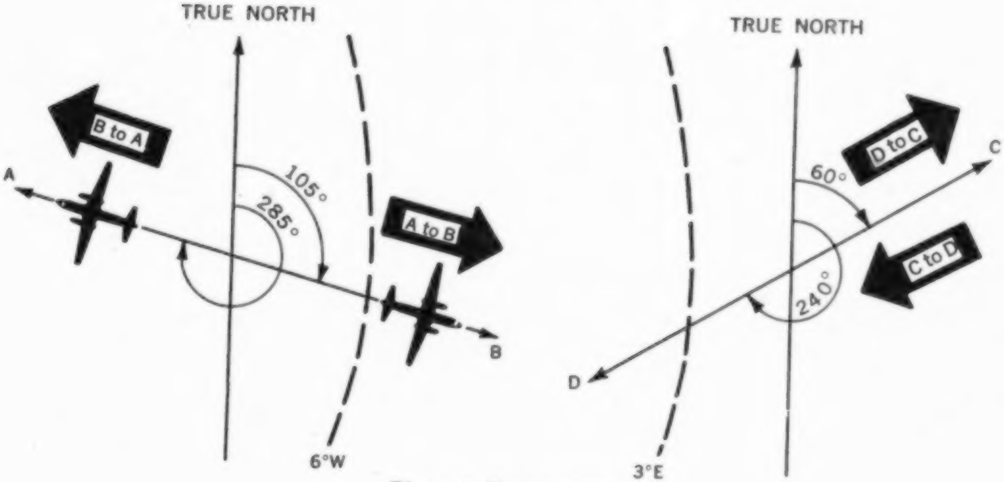
TRUE NORTH
B to A
A
105°
285°
A to B
B
6°W
TRUE NORTH
D to C
C
60°
C to D
240°
D
3°E

Figure 3. True courses

For navigational purposes directions are compared to True north; courses are measured *clockwise* in degrees from 0° to 360°. Thus, to travel from A to B, figure 3, a true course (TC), of 105° must be navigated. From B to A the TC is 285°.

……

5. What is the TC from D to C in figure 3?

6. What is the TC from C to D? This course may be found by adding 180° to the course from D to C. The courses from C to D and from D to C are called reciprocal courses.

……

The navigator uses a compass to help him find his course direction. He knows, however, that it does not point to the

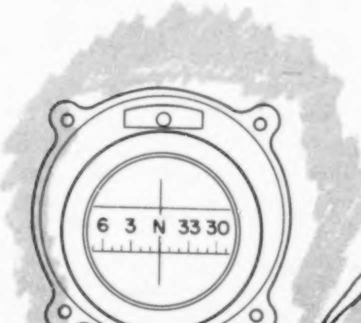

Figure 4. Compass

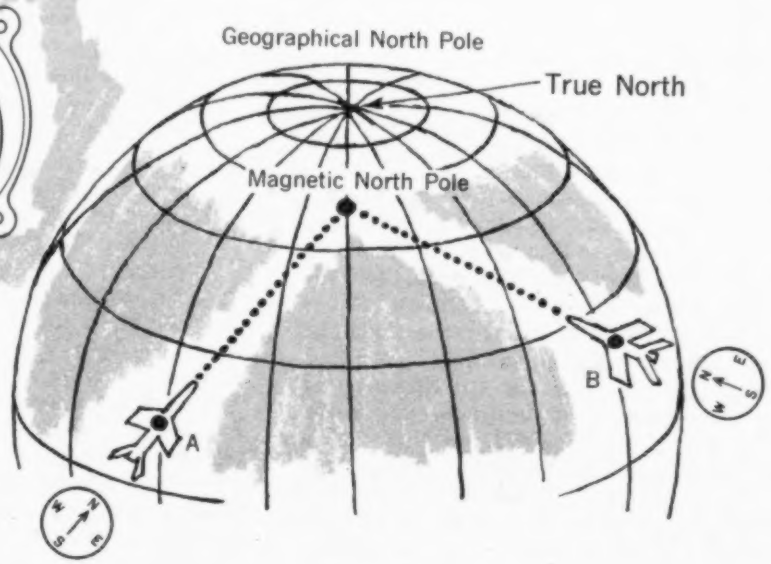
Geographical North Pole
True North
Magnetic North Pole
A
B
N
E
S
W
N
E
S
W

Figure 5. Magnetic pole

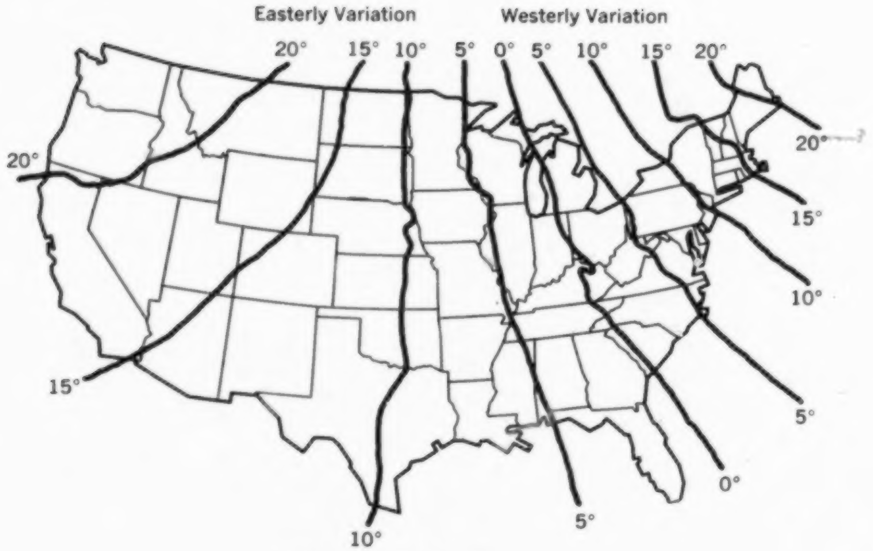

Figure 6. Variations

geographic north pole but rather to another position very near called the magnetic north pole, so he must correct his course measure. The angular difference between true north and magnetic north at a given place is called the variation at that place. To correct his course the navigator uses one of these formulas:

$$MC = TC + \text{Var. W., or}$$
$$MC = TC - \text{Var. E.}$$

MC is the magnetic course, TC is the true course, Var. W is the variation if the magnetic north pole is in a direction west of true north, and Var. E is the variation if the magnetic north pole is in a direction east of true north. The magnetic course is the reading he must use on his compass to follow the desired true course. Figure 6 shows how variation is distributed over the United States. The lines on this map are called isogonic lines. They join places which have the same variation. On the charts published by the United States Department of Commerce the isogonic lines appear as dashed lines with the amount of variation and the direction of variation marked at the upper and lower ends of the lines, as 6°E or 4°W. At a location where the variation is 6°E, the compass will read 0° or 360° when the magnetic course to true north is actually 6° west of that reading, or 354°; at a location where the variation is 4°W, the compass will read 0° or 360° when the magnetic course to true north is 4° to the east of 0° or 4°. (*see Figure 7*).

……

7. From Figure 8, what is the true course from A to B? Use a protractor.
8. What is the correction due to variation on the true course from A to B?
9. What is the magnetic course from A to B?
10. What is the correction, due to variation, necessary to travel a TC from C to D?
11. What MC must be used (C to D)?
12. In Figure 9, what magnetic course must be navigated and how far is it from Wood County airport to the New Lexington airport?
13. Shortly after take-off from the Wood County airport you cross a river (marked on your chart). You notice on your chart a prominent landmark to the left of your course, a school. Approximately how many degrees to the left of your course is the landmark from your position at the river?

……

A navigator must be able to estimate the measures of angles and directions. Even though this method of navigation, contact flying, or piloting, is not complicated, it does nevertheless, require some knowledge of mathematics.

Now we will study about a more advanced method of navigation. We can

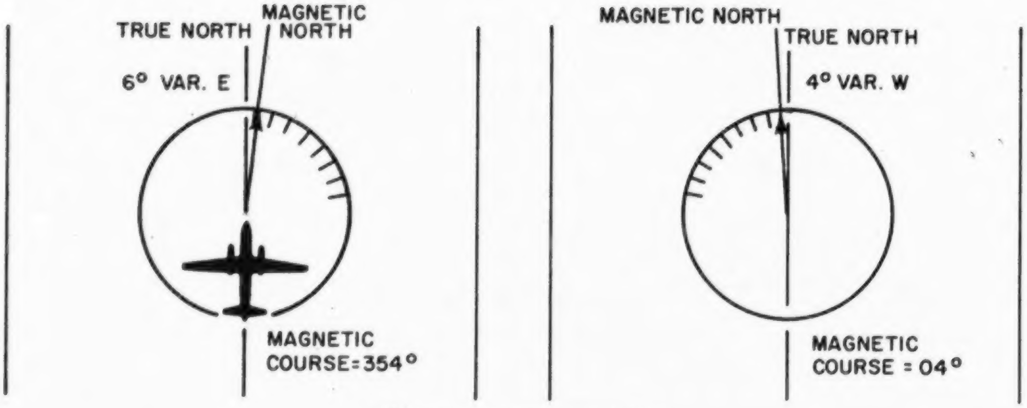
TRUE NORTH
MAGNETIC NORTH
6° VAR. E
MAGNETIC COURSE=354°
MAGNETIC NORTH
TRUE NORTH
4° VAR. W
MAGNETIC COURSE = 04°

Figure 7. Compass variation

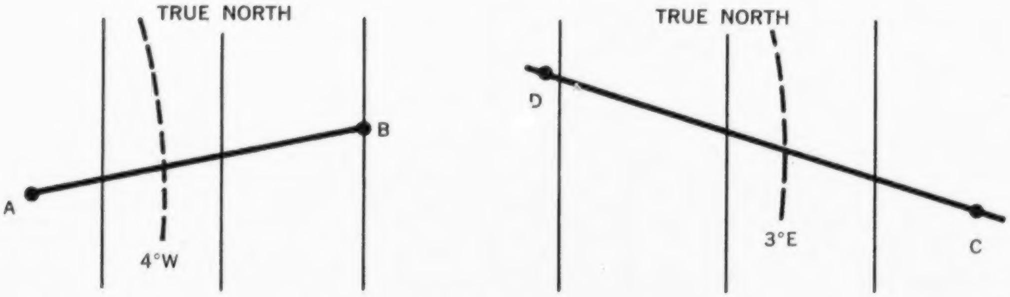
TRUE NORTH
A
B
4°W
TRUE NORTH
D
C
3°E

Figure 8. Magnetic courses

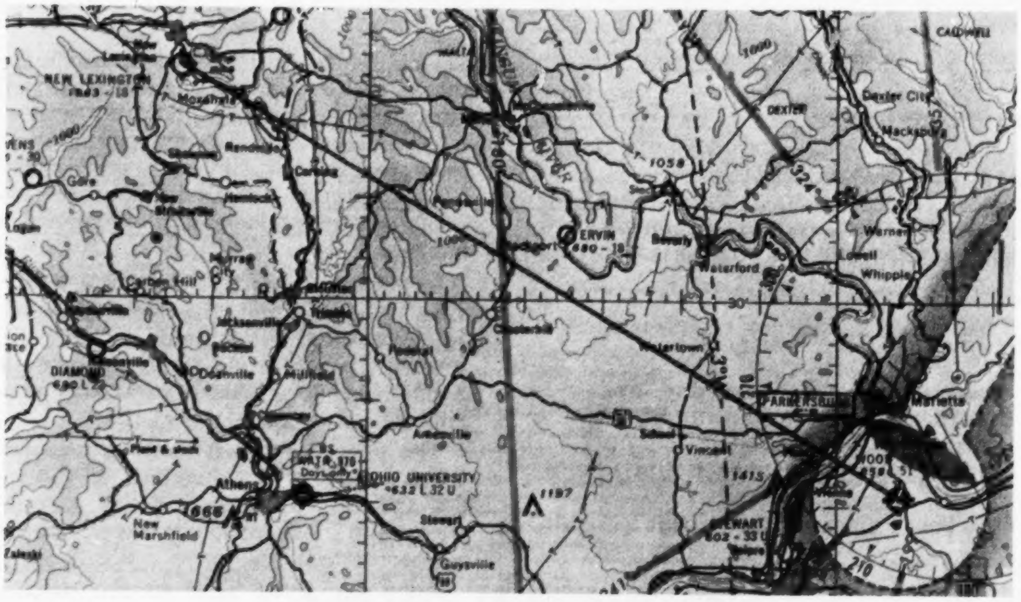
NEW LEXINGTON
ERVIN
Beverly
Waterford
Marietta
Athens
OHIO UNIVERSITY
New Marshfield
DIAMOND
Caldwell
Dexter City
Watertown
Lowell
Whipple
1058
30'

Figure 9. Huntington Sectional Aeronautical Chart

develop new ideas if we perform the following experiment and study its results carefully.

……

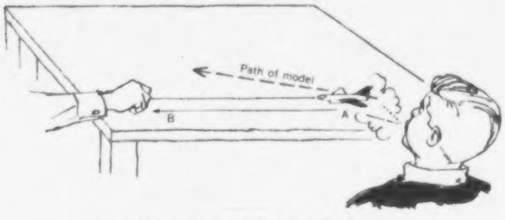

Figure 10. Path of plane

Experiment 1.

Materials:

string or thread
chalk
lightweight toy
smooth surface

Procedure:

Pull the string attached to the model slowly along a line drawn from A to B as shown in the diagram while blowing heavily on the model from one side. Repeat several times; blow lighter on some trials and heavier on others.

Observations:

Did the model follow directly behind your hand as you pulled and blew?
After a few trials, did you know what to expect before making the next trial?
What conclusion could you make about the path of the model as you blow on it and pulled?

……

Perhaps you could understand the results you obtained better if you knew about vectors, a mathematical way of representing the two forces which acted on the model.

……

Experiment 2.—Vector representation

Materials:

rubber bands
1 notebook snap ring
weight (approx. 8 oz.)
masking tape
4 straight pins
ruler
paper clips (3 or 4)
pencil
fibre board or card board about 24" x 36"

Procedure:

Test three rubber bands for equal strength (stretch) by the method shown in (I) of Figure 11. Bands of approximately the same strength will stretch the same under the weight. On the board draw CA approximately 3 inches and extend beyond for approximately 3 inches. Likewise draw CB 4 inches and extend for approximately 3 inches (unstretched length of the rubber band).

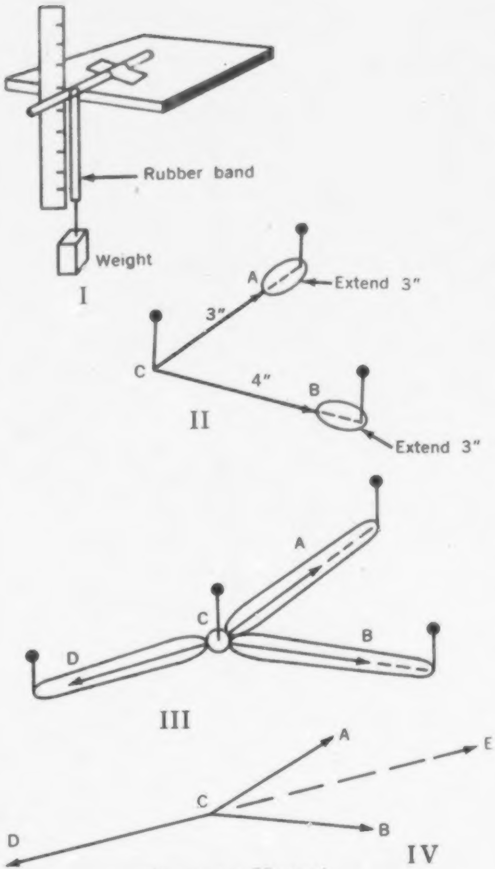

Figure 11. Vectors

Lay two rubber bands on the lines as shown in (II) and pin them in position so that they will stretch when pulled toward the pin at C. Stretch each of the bands and attach each to the notebook ring placed over the pin at C.

The *stretch* in each band represents a force acting in the direction of the rays CA and CB. These rays which represent forces and the direction of these forces are called "vectors".

Loop the third band in the notebook ring at C and stretch in the general direction of D, (III), until the pin at point C is centered in the ring.

Measure the "stretch" along the direction of D (*be sure to deduct the length of the unstretched band*). This is the force (vector) that is necessary to equalize the combined forces represented by vectors CA and CB. Extend DC in the direction of the dashed line and mark the amount of stretch at E so that CD = CE. You have discovered a very important relationship called the "resultant". It represents the one stretch (force) that would result from the action of the two stretches (forces) that were applied at the beginning of the experiment.

Repeat the experiment using different forces. Do the results seem to be similar?

……

Through the use of vectors to represent forces it is possible to find the resultant directly through mathematics. This is how it is done.

……

Problem:

Find the resultant of a force of 4 pounds to the east and 2 pounds to the south.

Solution:

1. Select a direction for north.
2. Select a length to represent a unit of force. 1 inch = 2 lb. will be used in this problem.
3. Draw vector AB and vector BC as shown in the following diagram.

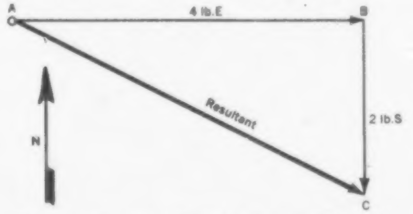

Figure 12. Resultant in vector triangle

4. Draw vector AC. This is the resultant.

……

Problems:

14. How long is the measure of vector AC? How many pounds of force does this represent? (1 in. = 2 lb.)
15. What is the general direction of vector AC?

This process of finding the resultant is called "vector addition." The Figure 12 is a vector triangle. Vector AC is called the sum of vector AB and vector BC.

When an aircraft in flight encounters the force of wind blowing across its course as in Figure 13 (first top frame) it will drift from its course. The second frame shows that the pilot must turn (head) his aircraft slightly into the wind (called crabbing), in order to prevent drifting off course.

In order to determine how much he must turn his aircraft into the wind (or crab) the pilot must be able to solve problems similar to the one which follows.

……

Problem:

A pilot whose aircraft's average speed is 150 mph wishes to travel a true course (TC), or resultant course, of 90°. He encounters a wind blowing from 240° (toward 60°) at 40 mph.

(a) In what direction must he head (turn) his aircraft to fly his intended course directly?

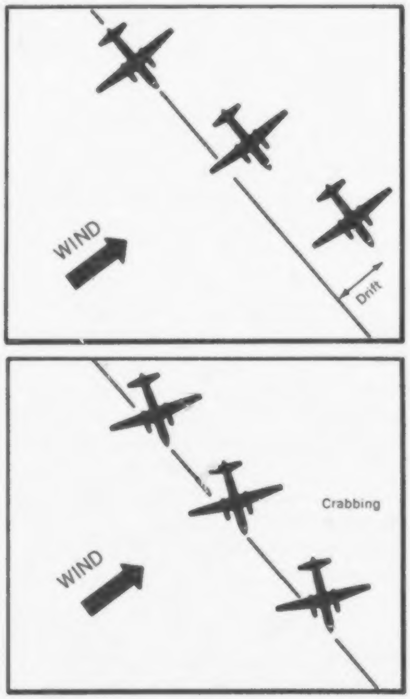

Figure 13. Affected course

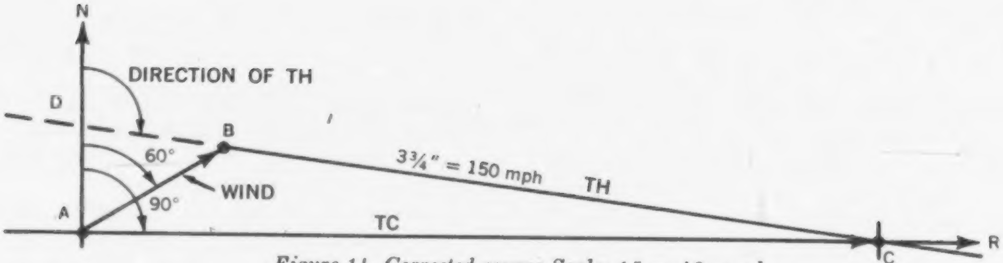

Figure 14. Corrected course Scale: 1" = 40 m.p.h.

(b) What will his resultant speed along the course be?

Solution: (See Figure 14)

1. Draw a line to represent north and mark a point on this line (A).
2. Draw a long line through point A to represent the direction of the intended course, AR at 90°. This is the direction of the resultant.
3. Select a convenient unit and draw the wind vector AB. (1" = 40 mph)
4. From B measure a vector $3\frac{3}{4}''$ long to represent 150 mph so that the end touches line AR at point C.
5. What is the direction of line BC? Measure for this direction (true heading, TH) at point D in the figure.
6. How long is segment AC? How many mph does this length represent? This will tell the speed he is traveling along his desired course.

The solution of this problem tells the pilot that he must head his aircraft in a direction of 98°, (crab to the right) and that his resultant speed will be approximately 180 mph due to the wind encountered (a tail wind).

……

16. A pilot wishes to travel a true course (TC) of 60°. The average speed of the aircraft he is flying is 120 MPH. He encounters of wind of 40 MPH blowing from a direction of 280°. In what direction must he head his aircraft (TH) in order to fly the desired course? How fast will his speed be along this course?
17. The desired course (TC) is 40°. If the average speed of the aircraft being flown is 160 MPH and a wind from the east, 90°, at 25 MPH is blowing, what is the heading (TH) necessary to maintain the TC. What will the speed along the TC be?

……

STARS AS SIGNPOSTS

One of the earliest references used by man in his travels to direct him from one place to another was the celestial dome over his head and the many heavenly bodies. Today, after many centuries of progress these bodies remain one of the most accurate and reliable natural means of ascertaining direction; boy scouts, sailors, aviators, and the man on the street still "look to the stars" for direction. Rarely is it possible to find a person who cannot locate the "Big Dipper" and the "North Star".

The use of celestial bodies as a means of navigation, requires some knowledge of the Earth and its relation to the huge imaginary dome over us which we are going to call the celestial sphere. A study of figure 16, a picture of the Earth and the celestial sphere, will help you develop some new ideas.

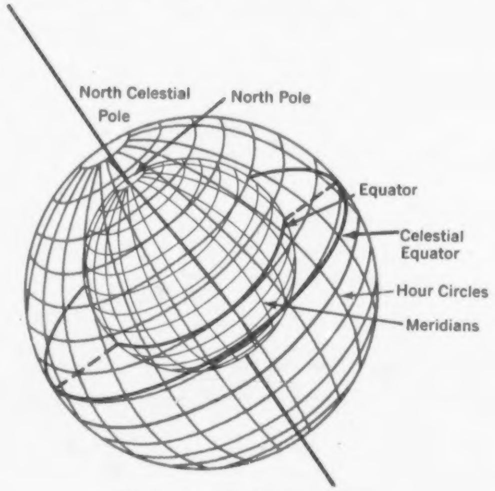

Figure 15. Celestial sphere

The Earth is divided by two imaginary sets of lines, lines of latitude and lines of longitude, the use of which makes it possible to identify any point on the sur-

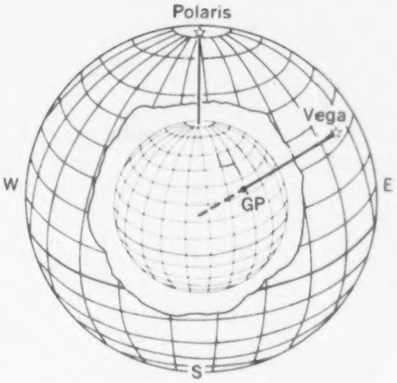

Figure 16. Celestial sphere and the Earth

George W. Mixter, Primer of Navigation (New York: D. Van Nostrand Company, Inc., 1960).

face of the Earth. The celestial sphere likewise is divided into two sets of lines which correspond to those on the Earth. Celestial parallels correspond to the parallels of latitude on the Earth; hour circles on the celestial sphere correspond to the terrestrial meridians or lines of longitude on Earth.

The terms geographic position (GP) and declination will be used frequently. See Figure 16. Geographic position can best be understood by imagining yourself to be at the center of a large transparent ball, the Earth; you then imagine a light bulb shining far out from the transparent ball. If you touch the point on the surface where the light comes through to you, then the point you touch is the GP of that light on the ball. The declination of a point on the celestial sphere is the central angle between the celestial parallel through the point and the celestial equator. It is measured the same way as terrestrial latitude. Since the diameter of the Earth is small as compared to the distance from the Earth to the sun and stars in the celestial sphere, the angle observed from the surface of the Earth is assumed to be the same as the angle formed at the center of the Earth by the projection from the heavenly body and the plane of the horizon, the plane of the equator, or the projection of the zenith to the center of the Earth.

The old saying, "X marks the spot", is the basic principle used in celestial navigation. The bars which are used to make the "X" are what the navigator designates as lines of position, abbreviated, LOP's. These lines of position may be located by finding ones position in terms of lines of latitude and lines of longitude.

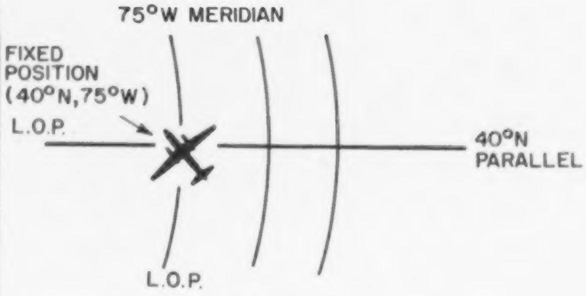

Figure 17. Lines of position

Finding latitude by the method called, "The noon sight of the altitude of the sun", is perhaps one of the easiest methods used. This means that the sun must be sighted as it crosses the meridian of the observer; the latitude of the observer then can be found by using the formula,

Latitude = Zenith distance + Declination,

or

$$L = z + d.$$

If you stand and look to the point in the sky directly over your head, the point you see is the zenith for your position. See Figure 18. To solve the formula, $L = z + d$, first find a value for z, the zenith distance, which is measured in degrees of arc. The number of degrees of arc is the same as the number of degrees in the central angle. From the figure you can see that the zenith forms an angle of 90° with the horizon, and z is a part of that angle, the other part of which is the altitude of the sun, that is,

$$z = 90^\circ - \text{altitude of the sun}$$

The altitude is measured with an instrument called a sextant. *(See Figure 19.)*

••

Problems:

18. An observer uses his sextant to measure the altitude of the sun. The altitude measure is found to be 68° 30′. Find z, the Zenith distance, in degrees.

(Find the desired answers for the following altitudes.)

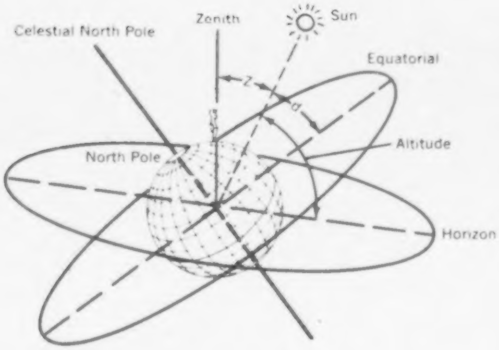
Celestial North Pole
Zenith
Sun
Equatorial
z
d
Altitude
North Pole
Horizon

Figure 18. Zenith distance

	Altitude measure	z
19.	63° 30′	
20.	70° 52′	
21.	48° 26′	
22.	80° 05′	

……

To complete the solution of the formula, L = z + d, a value for d, the declination of the sun, must be found. These values are listed in *The Air Almanac;* a portion of which has been reproduced for you to use on pages A7 and A8 in May-Aug. 1964.

……

Problem:

If the meridian altitude measure of the sun on July 16, 1964, is 68° 30′ and if the declination at noon on the date is found in the Air Almanac to be 21° 18′, what is the latitude of the position?

Solution:

L = z + d
z = 90° − altitude, or 21° 30′, therefore,
L = 21° 30′ + 21° 18′, or 42° 48′.
The latitude of the observer 42° 48′ N.

……

Problems:

Find the observer's latitude in each of the following:

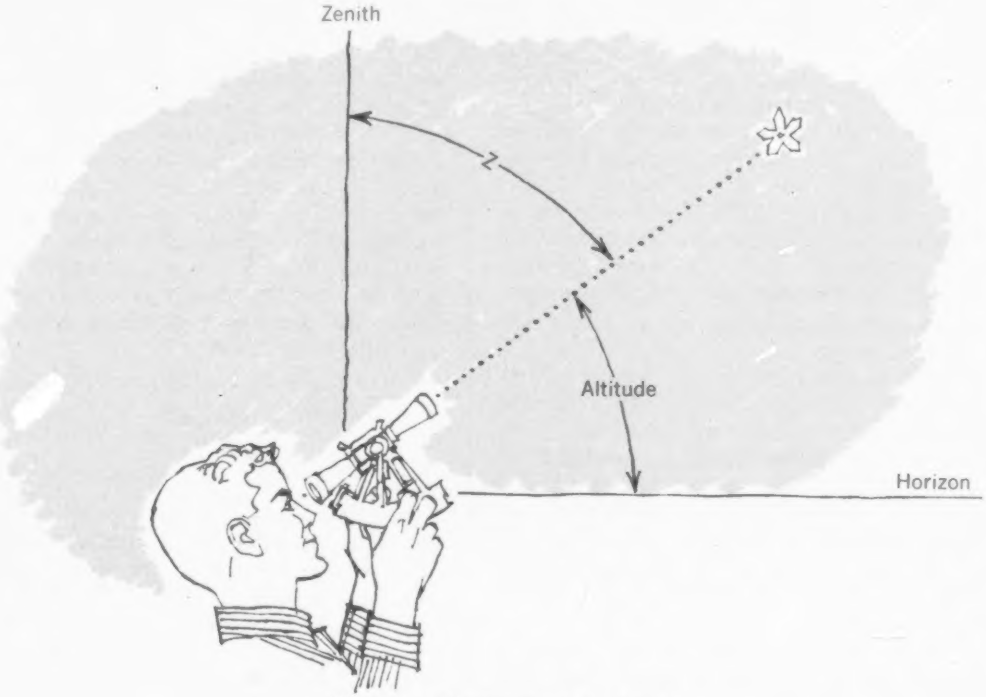
Zenith
z
Altitude
Horizon

Figure 19. Measurement of altitude

	Noon Meridian Altitude of Sun	Declination	Latitude
23.	65° 11′	15° 07′	
24.	40° 32′	20° 12′	
25.	82° 10′	23° 23′	

The meridian of the observer will be used as the first LOP. Since this is a "noon meridian altitude of the sun observation," the only other necessary measure needed is an accurate measure of time.

Time, the rotation of the Earth, and longitude are closely related. The navigator bases his work on a time measure called Greenwich Mean Time (GMT). *GMT is the same at any certain moment for any place on Earth.* That is, when it is 4:00 GMT in England, the time is 4:00 GMT in California, and the time is 4:00 GMT in New York. The Earth makes one rotation on its axis in 24 hours. The count begins when the sun crosses the International Date Line, an imaginary line which corresponds to the 180° meridian. The Earth rotates at a rate of 15° an hour. In 12 hours the Earth will rotate through an arc of,

12 x 15° or 180°.

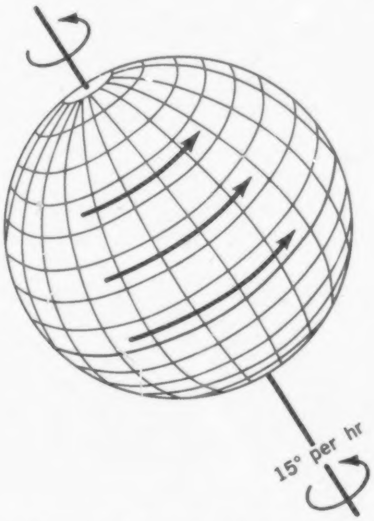

Figure 20. Rotation of the Earth

26. Through how many degrees of arc will the Earth rotate in (a) 5 hours; (b) 9 hours; (c) 15 hours; (d) 3 hours and 20 minutes; (e) 20⅔ hours; (f) 24 hours?

27. By using the symbols, A, for arc, h for hours, and r for the rate of rotation, write a formula for this relationship.

The following table gives a more detailed account of this relationship:

Table 1.—Arc-time relationships

Time	Arc
24^{h}	360°
1^{h}	15°
1^{m}	15′
4^{s}	1′
1^{s}	.25′

John C. Hill, II, Thomas F. Utegaard, and Gerard Riordan, Dutton's Navigation and Piloting (Annapolis, Maryland: United States Naval Institute, 1958), p. 367. The table is reproduced by permission from Dutton's Navigation and Piloting, Copyright © 1958 by U.S. Naval Institute, Annapolis, Maryland.

The Air Almanac has made use of this conversion table in making its record of the sun's position in periods of 10 minute intervals (GMT) as it transits the meridians of the Earth. By taking a "noon sight" of the sun, the longitude of your position can be determined directly from *The Air Almanac* under the column heading of "Sun GHA" which is adjacent to the column marked "GMT".

Example:

If the sun transits the meridian of your position at $17^{h}10^{m}$ GMT on January 1, 1964, your position of longitude as taken from *The Air Almanac* is 76° 40′ W. See table 3. Tables 2 and 3 are pages from *The Air Almanac.*

The line of longitude is then the second desired "line of position," necessary in finding a "fix" on a position.

The Air Almanac is published several times annually, to provide in a convenient form the astronomical data required for air navigation.

Table 2.—A.M. Longitudes

GREENWICH A. M. 1964 JANUARY 1 (WEDNESDAY)

GMT		SUN				ARIES		VENUS—3.4				JUPITER—2.1				SATURN 1.0				○ MOON			
		GHA		Dec.		GHA ♈		GHA		Dec.		GHA		Dec.		GHA		Dec.		GHA		Dec.	
h	m	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′
00	00	179	15	S23	06	99	41	146	34	S19	25	89	18	N 3	03	136	29	S15	49	336	34	N21	45
	10	181	45			102	12	149	04			91	49			138	59			338	58		44
	20	184	15			104	42	151	34			94	19			141	29			341	22		44
	30	186	45	•	•	107	12	154	04	•	•	96	49	•	•	144	00	•	•	343	46	•	43
	40	189	15			109	43	156	34			99	20			146	30			346	10		42
	50	191	45			112	13	159	04			101	50			149	00			348	34		41
01	00	194	15	S23	06	114	44	161	33	S19	24	104	21	N 3	03	151	31	S15	49	350	58	N21	40
	10	196	45			117	14	164	03			106	51			154	01			353	22		40
	20	199	15			119	44	166	33			109	21			156	32			355	46		39
	30	201	45	•	•	122	15	169	03	•	•	111	52	•	•	159	02	•	•	358	10	•	38
	40	204	15			124	45	171	33			114	22			161	32			0	34		37
	50	206	44			127	16	174	03			116	52			164	03			2	58		36
02	00	209	14	S23	05	129	46	176	33	S19	23	119	23	N 3	03	166	33	S15	48	5	22	N21	35
	10	211	44			132	17	179	03			121	53			169	03			7	46		35
	20	214	14			134	47	181	33			124	24			171	34			10	10		34
	30	216	44	•	•	137	17	184	02	•	•	126	54	•	•	174	04	•	•	12	34	•	33
	40	219	44			139	48	186	32			129	24			176	34			14	58		32
	50	221	44			142	18	189	02			131	55			179	05			17	22		31
03	00	224	14	S23	05	144	49	191	32	S19	22	134	25	N 3	03	181	35	S15	48	19	46	N21	30
	10	226	44			147	19	194	02			136	55			184	06			22	10		29
	20	229	14			149	49	196	32			139	26			186	36			24	34		29
	30	231	44	•	•	152	20	199	02	•	•	141	56	•	•	189	06	•	•	26	58	•	28
	40	234	14			154	50	201	32			144	27			191	37			29	22		27
	50	236	44			157	21	204	02			146	57			194	07			31	46		26
04	00	239	14	S23	05	159	51	206	31	S19	21	149	27	N 3	03	196	38	S15	48	34	10	N21	25
	10	241	44			162	21	209	01			151	58			199	08			36	34		24
	20	244	14			164	52	211	31			154	28			201	38			38	59		23
	30	246	44	•	•	167	22	214	01	•	•	156	58	•	•	204	09	•	•	41	23	•	22
	40	249	14			169	53	216	31			159	29			206	39			43	47		21
	50	251	44			172	23	219	01			161	59			209	09			46	11		21
05	00	254	14	S23	05	174	54	221	31	S19	20	164	30	N 3	03	211	40	S15	48	48	35	N21	20
	10	256	43			177	24	224	01			167	00			214	10			50	59		19
	20	259	13			179	54	226	30			169	30			216	40			53	23		18
	30	261	43	•	•	182	25	229	00	•	•	172	01	•	•	219	11	•	•	55	47	•	17
	40	264	13			184	55	231	30			174	31			221	41			58	11		16
	50	266	43			187	26	234	00			177	01			224	12			60	35		15
06	00	269	13	S23	05	189	56	236	30	S19	19	179	32	N 3	03	226	42	S15	48	62	59	N21	14
	10	271	43			192	26	239	00			182	02			229	12			65	23		13
	20	274	13			194	57	241	30			184	33			231	43			67	48		12
	30	276	43	•	•	197	27	244	00	•	•	187	03	•	•	234	13	•	•	70	12	•	11
	40	279	13			199	58	246	30			189	33			236	43			72	36		10
	50	281	43			202	28	248	59			192	04			239	14			75	00		09
07	00	284	13	S23	04	204	58	251	29	S19	19	194	34	N 3	04	241	44	S15	48	77	24	N21	09
	10	286	43			207	29	253	59			197	04			244	14			79	48		08
	20	289	13			209	59	256	29			199	35			246	45			82	12		07
	30	291	43	•	•	212	30	258	59	•	•	202	05	•	•	249	15	•	•	84	36	•	06
	40	294	13			215	00	261	29			204	36			251	46			87	00		05
	50	296	43			217	30	263	59			207	06			254	16			89	24		04
08	00	299	13	S23	04	220	01	266	29	S19	18	209	36	N 3	04	256	46	S15	48	91	49	N21	03
	10	301	43			222	31	268	59			212	07			259	17			94	13		02
	20	304	13			225	02	271	28			214	37			261	47			96	37		01
	30	306	42	•	•	227	32	273	58	•	•	217	08	•	•	264	17	•	•	99	01	21	00
	40	309	12			230	03	276	28			219	38			266	48			101	25	20	59
	50	311	42			232	33	278	58			222	08			269	18			103	49		58
09	00	314	12	S23	04	235	03	281	28	S19	17	224	39	N 3	04	271	49	S15	48	106	13	N20	57
	10	316	42			237	34	283	58			227	09			274	19			108	38		56
	20	319	12			240	04	286	28			229	39			276	49			111	02		55
	30	321	42	•	•	242	35	288	58	•	•	232	10	•	•	279	20	•	•	113	26	•	54
	40	324	12			245	05	291	28			234	40			281	50			115	50		53
	50	326	42			247	35	293	57			237	11			284	20			118	14		52
10	00	329	12	S23	04	250	06	296	27	S19	16	239	41	N 3	04	286	51	S15	48	120	38	N20	51
	10	331	42			252	36	298	57			242	11			289	21			123	02		50
	20	334	12			255	07	301	27			244	42			291	51			125	27		49
	30	336	42	•	•	257	37	303	57	•	•	247	12	•	•	294	22	•	•	127	51	•	48
	40	339	12			260	07	306	27			249	42			296	52			130	15		47
	50	341	42			262	38	308	57			252	13			299	23			132	39		46
11	00	344	12	S23	04	265	08	311	27	S19	15	254	43	N 3	04	301	53	S15	48	135	03	N20	45
	10	346	42			267	39	313	56			257	14			304	23			137	27		44
	20	349	12			270	09	316	26			259	44			306	54			139	52		42
	30	351	42	•	•	272	40	318	56	•	•	262	14	•	•	309	24	•	•	142	16	•	41
	40	354	12			275	10	321	26			264	45			311	54			144	40		40
	50	356	42			277	40	323	56			267	15			314	25			147	04		39

Moon's P. in A.

° Alt.	+ Corr.
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☉ Sun

SD 16′

Moon

SD 16′

Age 15

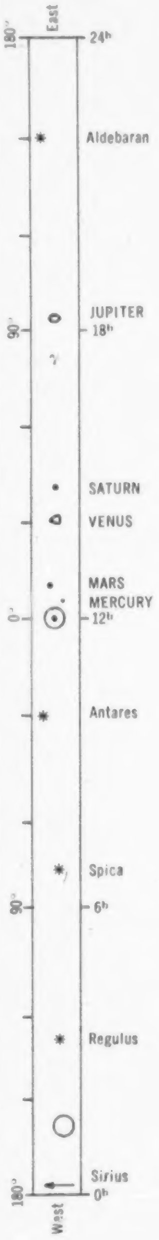

Table 3.—P.M. Longitudes

GREENWICH P. M. 1964 JANUARY 1 (WEDNESDAY)

GMT		SUN		ARIES	VENUS—3.4		JUPITER—2.1		SATURN 1.0		○ MOON	
		GHA	Dec	GHA ♈	GHA	Dec	GHA	Dec	GHA	Dec	GHA	Dec
h	m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
12	00	359 12	S23 03	280 11	326 26	S19 14	269 45	N 3 04	316 55	S15 48	149 28	N20 38
	10	1 41		282 41	328 56		272 16		319 26		151 53	37
	20	4 11		285 12	331 26		274 46		321 56		154 17	36
	30	6 41	• •	287 42	333 56	• •	277 17	• •	324 26	• •	156 41	• 35
	40	9 11		290 12	336 26		279 47		326 57		159 05	34
	50	11 41		292 43	338 55		282 17		329 27		161 29	33
13	00	14 11	S23 03	295 13	341 25	S19 14	284 48	N 3 04	331 57	S15 48	163 54	N20 32
	10	16 41		297 44	343 55		287 18		334 28		166 18	31
	20	19 11		300 14	346 25		289 48		336 56		168 42	30
	30	21 41	• •	302 44	348 55	• •	292 19	• •	339 29	• •	171 06	• 29
	40	24 11		305 15	351 25		294 49		341 59		173 30	27
	50	26 41		307 45	353 55		297 20		344 29		175 55	26
14	00	29 11	S23 03	310 16	356 25	S19 13	299 50	N 3 04	347 00	S15 47	178 19	N20 25
	10	31 41		312 46	358 54		302 20		349 30		180 43	24
	20	34 11		315 17	1 24		304 51		352 00		183 07	23
	30	36 41	• •	317 47	3 54	• •	307 21	• •	354 31	• •	185 32	• 22
	40	39 11		320 17	6 24		309 51		357 01		187 56	21
	50	41 41		322 48	8 54		312 22		359 31		190 20	20
15	00	44 11	S23 03	325 18	11 24	S19 12	314 52	N 3 04	2 02	S15 47	192 44	N20 19
	10	46 41		327 49	13 54		317 23		4 32		195 08	17
	20	49 11		330 19	16 24		319 53		7 03		197 33	16
	30	51 40	• •	332 49	18 54	• •	322 23	• •	9 33	• •	199 57	• 15
	40	54 10		335 20	21 23		324 54		12 03		202 21	14
	50	56 40		337 50	23 53		327 24		14 34		204 45	13
16	00	59 10	S23 03	340 21	26 23	S19 11	329 55	N 3 04	17 04	S15 47	207 10	N20 12
	10	61 40		342 51	28 53		332 25		19 34		209 34	11
	20	64 10		345 21	31 23		334 55		22 05		211 58	09
	30	66 40	• •	347 52	33 53	• •	337 26	• •	24 35	• •	214 22	• 08
	40	69 10		350 22	36 23		339 56		27 06		216 47	07
	50	71 40		352 53	38 53		342 26		29 36		219 11	06
17	00	74 10	S23 02	355 23	41 23	S19 10	344 57	N 3 05	32 06	S15 47	221 35	N20 05
	10	76 40		357 54	43 52		347 27		34 37		224 00	04
	20	79 10		0 24	46 22		349 57		37 07		226 24	02
	30	81 40	• •	2 54	48 52	• •	352 28	• •	39 37	• •	228 48	• 01
	40	84 10		5 25	51 22		354 58		42 08		231 12	20 00
	50	86 40		7 55	53 52		357 29		44 38		233 37	19 59
18	00	89 10	S23 02	10 26	56 22	S19 09	359 59	N 3 05	47 09	S15 47	236 01	N19 58
	10	91 40		12 56	58 52		2 29		49 39		238 25	57
	20	94 10		15 26	61 22		5 00		52 09		240 50	55
	30	96 40	• •	17 57	63 52	• •	7 30	• •	54 40	• •	243 14	• 54
	40	99 10		20 27	66 21		10 01		57 10		245 38	53
	50	101 39		22 58	68 51		12 31		59 40		248 02	52
19	00	104 09	S23 02	25 28	71 21	S19 08	15 01	N 3 05	62 11	S15 47	250 27	N19 51
	10	106 39		27 58	73 51		17 32		64 41		251 51	49
	20	109 09		30 29	76 21		20 02		67 11		255 15	48
	30	111 39	• •	32 59	78 51	• •	22 32	• •	69 42	• •	257 40	• 47
	40	114 09		35 30	81 21		25 03		72 12		260 04	46
	50	116 39		38 00	83 51		27 33		74 43		262 28	45
20	00	119 09	S23 02	40 31	86 21	S19 08	30 04	N 3 05	77 13	S15 47	264 53	N19 43
	10	121 39		43 01	88 50		32 34		79 43		267 17	42
	20	124 09		45 31	91 20		35 04		82 14		269 41	41
	30	126 39	• •	48 02	93 50	• •	37 35	• •	84 44	• •	272 06	• 40
	40	129 09		50 32	96 20		40 05		87 14		274 30	38
	50	131 39		53 03	98 50		42 35		89 45		276 54	37
21	00	134 09	S23 02	55 33	101 20	S19 07	45 06	N 3 05	92 15	S15 47	279 19	N19 36
	10	136 39		58 03	103 50		47 36		94 45		281 43	35
	20	139 09		60 34	106 20		50 07		97 16		284 07	34
	30	141 39	• •	63 04	108 50	• •	52 37	• •	99 46	• •	286 32	• 32
	40	144 09		65 35	111 19		55 07		102 17		288 56	31
	50	146 39		68 05	113 49		57 38		104 47		291 20	30
22	00	149 09	S23 01	70 35	116 19	S19 06	60 08	N 3 05	107 17	S15 47	293 45	N19 29
	10	151 38		73 06	118 49		62 38		109 48		296 09	27
	20	154 08		75 36	121 19		65 09		112 18		298 33	26
	30	156 38	• •	78 07	123 49	• •	67 39	• •	114 48	• •	300 58	• 25
	40	159 08		80 37	126 19		70 10		117 19		303 22	24
	50	161 38		83 07	128 49		72 40		119 49		305 47	22
23	00	164 08	S23 01	85 38	131 19	S19 05	75 10	N 3 05	122 20	S15 47	308 11	N19 21
	10	166 38		88 08	133 48		77 41		124 50		310 35	20
	20	169 08		90 39	136 18		80 11		127 20		313 00	18
	30	171 38	• •	93 09	138 48	• •	82 41	• •	129 51	• •	315 24	• 17
	40	174 08		95 40	141 18		85 12		132 21		317 48	16
	50	176 38		98 10	143 48		87 42		134 51		320 13	15

Lat.	Sunrise		Twilight	Moonrise		Diff.
N						
°	h	m	m	h	m	m
72			79			•
70			134			•
68			166	15	52	•
66	10	30	96	16	33	55
64	09	51	76	17	02	49
62	09	24	64	17	23	46
60	09	03	57	17	40	43
58	08	46	51	17	55	42
56	08	32	47	18	07	40
54	08	19	44	18	18	39
52	08	08	41	18	27	38
50	07	59	38	18	36	38
45	07	38	34	18	54	36
40	07	22	30	19	09	34
35	07	08	28	19	21	33
30	06	56	26	19	32	33
20	06	35	24	19	51	31
10	06	17	23	20	07	30
0	06	00	23	20	22	28
10	05	42	23	20	37	27
20	05	23	24	20	53	26
30	05	02	27	21	12	24
35	04	49	30	21	22	23
40	04	34	33	21	34	22
45	04	16	37	21	48	21
50	03	54	44	22	06	19
52	03	44	48	22	14	18
54	03	32	53	22	23	17
56	03	18	61	22	33	16
58	03	01	73	22	45	14
60	02	42	97	22	59	13
S						

Lat.	Sunset		Twilight	Moonset		Diff.
N						
°	h	m	m	h	m	m
72			79			•
70			134			•
68			166	12	32	•
66	13	37	95	11	50	05
64	14	16	76	11	21	11
62	14	43	64	11	00	14
60	15	04	57	10	42	16
58	15	21	51	10	27	18
56	15	35	47	10	14	19
54	15	47	44	10	03	20
52	15	58	41	09	53	21
50	16	08	38	09	44	22
45	16	28	34	09	25	23
40	16	44	30	09	09	24
35	16	58	28	08	56	25
30	17	11	26	08	45	26
20	17	31	24	08	25	27
10	17	50	23	08	08	28
0	18	07	23	07	52	29
10	18	24	23	07	35	31
20	18	43	24	07	18	32
30	19	04	27	06	58	33
35	19	17	30	06	46	34
40	19	32	33	06	32	34
45	19	50	37	06	16	35
50	20	12	44	05	56	37
52	20	22	48	05	47	38
54	20	34	53	05	36	38
56	20	48	61	05	24	39
58	21	04	73	05	10	40
60	21	24	97	04	53	42
S						

Problems:

28. Use *The Air Almanac* pages and find the longitude of an observer who takes a sight of the sun as it transits his position at 20 h 00 m GMT, on January 1, 1964. Try this one!

29 A navigator takes a "noon sight" as the sun transits his position and records the following:

   Date January 1, 1964
   Time 17 h 00 m GMT

   Altitude of the sun in transit 73° 02′. Find the latitude and longitude of the aircraft.

30. If the TC of the aircraft is approximately 270°, what large American city is the aircraft approaching provided your original position or point of reference is given by the latitude and longitude in problem 29. Use all you have found out to see if you can answer this one.

31. Shortly after take off from an airport near a large American city an aircraft made a "moon meridian altitude" sight and recorded the following:

   Date January 1, 1964
   Time 07 h 00 m GMT

   Altitude of the moon in transit 72° 09′. If the TC of the aircraft is 320°, from what city does the aircraft appear to be departing?

Experiment:

"Make a Sextant" — measure the altitude of the moon and Polaris.

Materials:

large drinking straw
protractor
small weight
pin
thread
masking tape

Gaylord Johnson and Irving Adler, Discover the Stars (New York: Sentinel, 1954). Directions are used by permission of Sentinel Books Publishers, Inc.

Procedure:

With masking tape, fasten the protractor to the straw as shown. The 90° mark and the arrow which marks the center of the

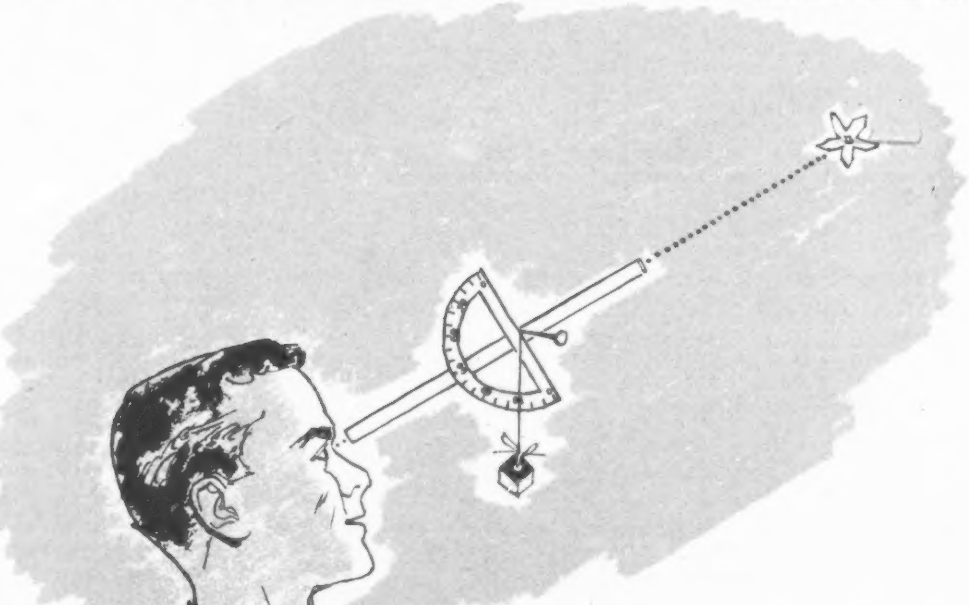

Figure 21. Simple transit

base should be in line with the straw. Pin the weight suspended by thread from the center of the straw at the base of the protractor, as shown. The angle of elevation of a heavenly body (the moon) can now be determined by reading from the scale.

CAUTION!! DO NOT use this instrument to sight the sun, as it is never advisable to look directly at the sun. By doing so, you may cause severe damage to your eyes, damage which may be immediate in some cases and delayed in others. *REMEMBER! DO NOT SHOOT THE SUN!*

……

32. Use your sextant to shoot the moon day or night, at approximately one hour intervals and record your findings. At what point, direction, did it appear to have its maximum elevation?
33. Find Polaris, the North Star, and find its elevation. The elevation of Polaris is approximately the latitude of your position. Why is this true? Study the figure.

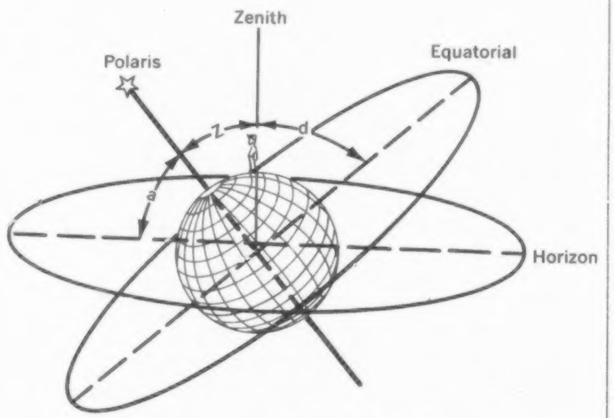

Figure 22. Elevation of Polaris

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The celestial navigation presented here has been greatly simplified. Procedures which have greater utility are used by professional navigators; they demand a greater understanding of scientific principles and of mathematics.

Celestial navigation has a future in space navigation. Through television onboard and the use of special sextants, it is hoped that on-board navigation and midcourse guidance can be accomplished on space craft. These instruments are expected to be able to determine the angle between guide stars and the moon or Earth or other planets to a few seconds of arc.

Even though navigation by celestial means has been successfully used for centuries, disadvantages are evident. One is the weather. You cannot navigate by a star you cannot see. To combat this weakness the United States is launching artificial star satellites, the Transit series, for experimentation on satellite navigation. Navigational information, unaffected by weather conditions, is available from the satellite at all times through the use of a special instrument called a radio sextant or by using time signals and a radar locating phenomenon known as the Doppler Shift.

The Doppler principle was first explained by an Austrian physicist, Christian Doppler, in 1842. Assume a light or sound source is *moving*. He showed that if light or sound waves are aproaching an observer, they will reach him with a greater rate than they would have had the source been stationary. This change in rate amounts to increasing the frequency. He noted also that there was an increase in frequency when a moving observer approached the stationary source emitting the waves, but the frequency differed from the first case. When the source or observer recedes from the other, there is a comparable decrease in frequency.

The principle can perhaps best be explained by considering the case of a tuning fork moving toward an observer at the rate of 1650 cm. per second while giving off vibrations at the rate of 440 vibrations per second. The velocity of sound is approximately 33,000 cm. per second. The actual length of one wave is then,

$\lambda = \frac{v}{n}$, where λ represents one wave length,
v is the velocity of sound,

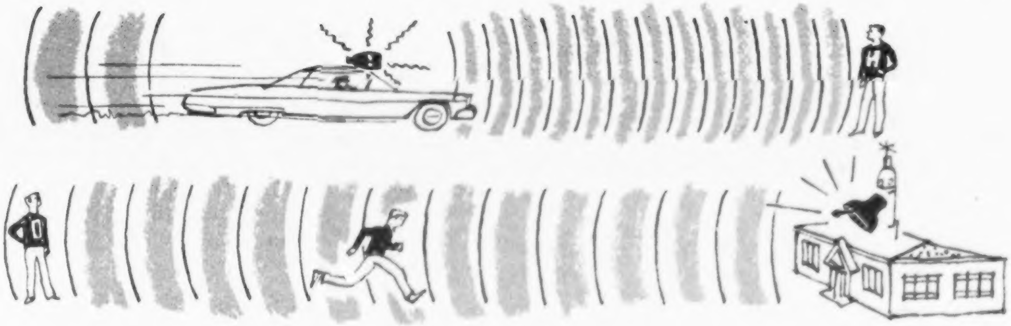

Figure 23. Doppler's principle

and

n is the number of vibrations per second. Therefore,

$$\lambda = \frac{33{,}000}{440} \text{ or } 75 \text{ cm. (Wave length)}$$

With the fork vibrating at 440 vibrations per second, (vps), the time required for one complete vibration is $\frac{1}{440}$ sec. The distance the fork will travel in $\frac{1}{440}$ sec. will be

$$d = \frac{1}{440} \times 1650 \text{ cm.} = \frac{1650 \text{ cm.}}{440} \text{ or } 3.75 \text{ cm}$$

This means that each wave will be shortened by 3.75 cm. or each wave will now be.

$$75 \text{ cm.} - 3.75 \text{ cm.} = 71.25 \text{ cm.}$$

The velocity of sound is always the same in air whether given off by a source at rest or while moving

$$v = n\lambda \text{ or } n = \frac{v}{\lambda}, \text{ where}$$

v is the velocity of sound in air, n is the frequency (vps), and λ is the wave length. Therefore,

$$n = \frac{33{,}000}{71.25} = 463.1 \text{ vps. (frequency)}$$

This represents an increase of the frequency over that of the source when at rest (440 vps).

Now let us consider an example where the observer moves toward the source. In one second 440 vibrations reach the observer plus the number of waves included in the distance the observer has traveled, or

$$440 + \frac{1650}{75} = 440 + 22, \text{ or } 462 \text{ vps.}$$

This represents an increase of 22 vps over the frequency when both the source and observer were at rest.

The equations,

$$n_o = \frac{n\,v}{v \mp v_s}, \text{ and}$$

$$n_{o'} = n\left(1 \pm \frac{v_o}{v}\right), \text{where}$$

n_o is the frequency as heard by a stationary observer, n is the actual frequency of the sounding body, v_s the velocity of the sounding body and v the velocity of sound in air. $n_{o'}$ is the frequency as heard when the observer is in motion; v_o in the second equation is the velocity of the observer. In the first equation, the (−) sign is used when the sound source is approaching the observer; the (+) sign is used when the sound source is receding. In the second equation, the (+) sign indicates that the observer is approaching the sound source; the (−) sign indicates that he is moving away from the sound source.

Samuel Robinson Williams, Foundations of College Physics (New York: Ginn and Company, 1937), p. 208. Permission to use the formula and sample problems was granted by Ginn and Company.

Problem:

34. A fire engine answering a distress call is traveling at a rate of 60 feet per second and sounding its horn which emits a frequency of 280 cycles per second. What is the frequency of the horn as heard by an observer in front of him?

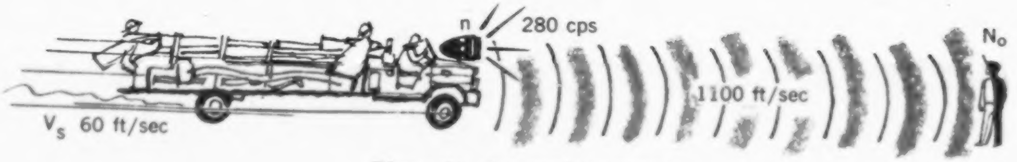

Figure 24. Approaching sound

Solution:
The sound source is approaching the observer, therefore,

$$n_o = \frac{nv}{v - v_s}.$$

v, the velocity of sound in air, is 1100 feet per second.

n_o = ______ cycles per second.

……

In the tracking of satellites by using the Doppler principle, the ground station sends out a signal to the satellite. The satellite upon receiving the signal immediately rebroadcasts the signal back to the ground station. When the satellite is approaching the ground station, the frequency received from it by the ground station is increased due to the Doppler effect. This difference in frequency between the original frequency and the frequency received by the ground station, known as the Doppler shift, can be measured, and from this measurement the velocity of the satellite can be computed.

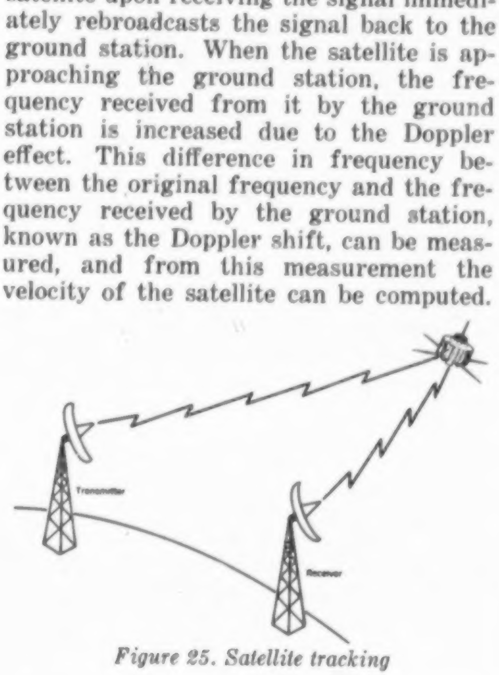

Figure 25. Satellite tracking

Let us study the formula,

$$n_o = \frac{nv}{v - v_s},$$

to see how it may be applied to satellite tracking. First, the signals are electromagnetic waves which *travel with the speed of light,* so, instead of v, the velocity of sound, the velocity of light, c, will be used. Second, since the signal must travel from the ground source to the satellite and return, $2v_s$ must be considered. With these changes the formula now becomes,

$$n_o = \frac{nc}{c - 2v_s},$$

where, n_o is the observed frequency returned, n is the original frequency transmitted, c is the velocity of light (186,000 miles per second), and v_s is the velocity of the satellite. We can find the Doppler shift, or sometimes called "beat frequency", (F) by finding the difference between the frequency returned, n_o, and the original frequency transmitted, n, by subtracting n from both sides of the formula and simplifying the result.

$$F = n_o - n = \frac{nc}{c - 2v_s} - n, \text{ and}$$

$$F = n_o - n = \frac{2nv_s}{c - 2v_s}.$$

Now, the difference between the speed of light, c, and twice the velocity of the satellite, $2v_s$ and the speed of light is so small, the denominator, $c - 2v_s$, can for all practical purposes be assumed to be the same as the speed of light, therefore,

$$F = n_o - n = \frac{2nv_s}{c}.$$

This is one formula, based on the Doppler principle, that is used to determine the speed of spacecraft, aircraft, or automobiles. The radar units that you see on the highways that are used to monitor traffic work on the same principle; the signal that is received from the vehicle is a reflected signal, however, rather than a signal that has been rebroadcasted.

Here are two problems for you to try.

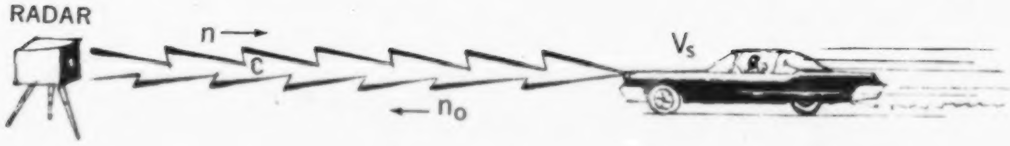

Figure 26. Radar control

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Problems:

35. A police radar unit transmits a signal of 100 megacycles and receives a reflected signal from an auto. If this "beat frequency", $n_o - n$, is 20 cycles per second, what is the speed of the oncoming auto?

Solution:

Given:

$n_o - n = 20$ cycles per second

$n = 100$ megacycles per second $= 100 \times 10^6$ cps $= 10^8$ cps.

$c = 186{,}000$ miles per second or 1.86×10^5 mi. per sec.

$$F = n_o - n = \frac{2nv_s}{c}, \text{ or,}$$

$$20 = \frac{2 \cdot 10^8 \cdot v_s}{1.86 \cdot 10^5}.$$ Complete the solution.

What is speed of the auto in mph?

36. The same radar unit, (problem 42), is used to check the speed of traffic in a 35 mph zone. If the Beat frequency observed from an oncoming car is 10 cycles per second, is the car within the legal limit? What is his speed?

……

A similar technique is applied to find the speed for tracking of the Transit Series and other satellites.

Another important phase of tracking involves finding the position of the satellite in the plane of its orbit. This is important, for, if the satellite is to be useful, the exact position of the satellite must be known at all times as well as the position it is expected to have at any future time.

The circular orbit has often been suggested as possibly the best orbit to use for the navigation satellites. Assuming that the satellite has been successfully placed in an orbit about the Earth, and that its orbit has been determined through observation by optical and electronic means, to be circular, then its position at a certain time can be computed.

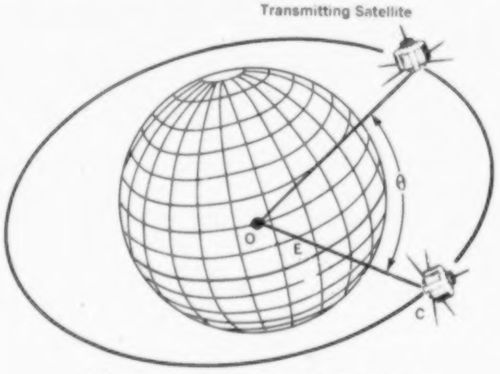


Figure 27. A satellite of the Earth

First, a reliable reference point must be selected, such as line OEC. By using the formula,

$$\theta = \omega t.$$

where θ is the angle formed at the center of the Earth, (0); ω is the angular velocity expressed in degrees per minute, and t is the time in minutes. Here is an example.

Example:

The tracking of a satellite revealed that the satellite has a circular orbit and has an angular velocity of 4° per minute. If its position was at the reference point C at $12^h\,30^m$ GMT, what is its position at $13^h\,00^m$? (by angle measure from the reference point).

Solution:

The measure of the Central angle at 0 may be found by solving the formula,

$\theta = \omega t.$

$\omega = 4°$ per minute, and $t = 30$ minutes, therefore

$\theta = 4° \cdot 30$, or $120°$.

Problems:

Find the central angle formed in each of the following orbits if:

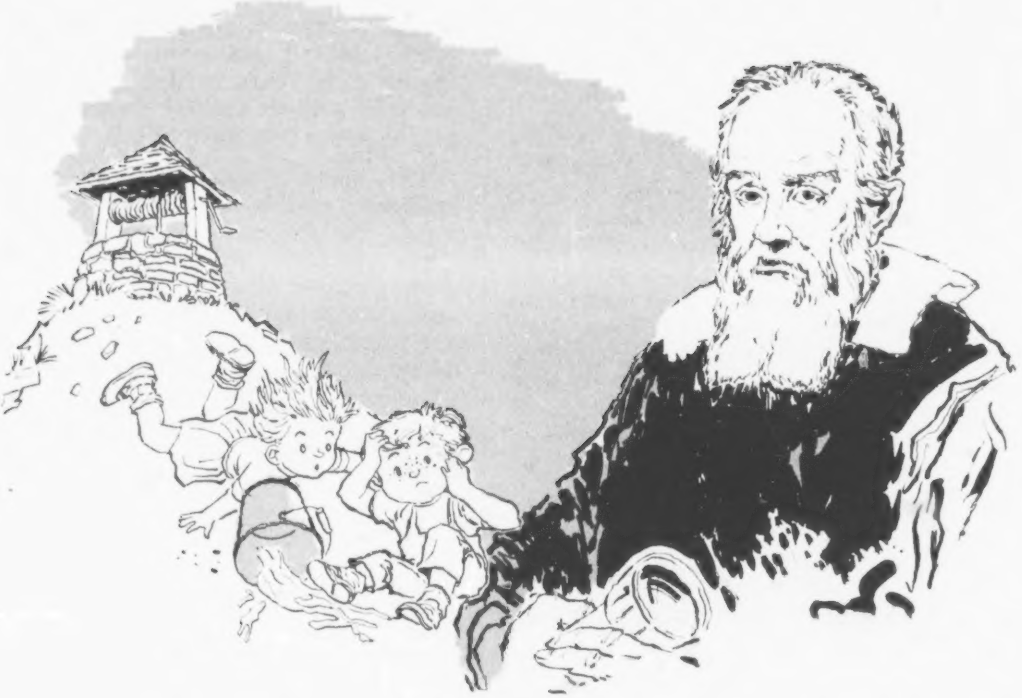
37. $\omega = 3°$ per min.; $t = 50$ min.
38. $\omega = 4°$ per min.; $t = 1$ hr.
39. $\omega = \frac{1}{4}°$ per min.; $t = 12$ hr.
40. $\omega = \frac{1}{4}°$ per min.; $t = 24$ hr.
41. Explain your answer for number 40.

By using the procedure just explained, the position of a satellite in its orbit can be computed and relayed by a ground station to any aircraft needing the information.

According to the latest publications, navigation by satellite is still in the experimental stage.

Several theories have been proposed regarding the best way to use these navigation satellites. One suggested possibility favors placing eight satellites in synchronous orbits, each at an altitude of 22,300 miles with orbital velocities of 6890 miles per hour, and in orbital planes inclined at an angle of 11.5° to the equatorial plane. These satellites would each appear to remain over a common meridian, traveling a path 11.5° north and then 11.5° south of the Equator. Another proposal would involve a system of four satellites in polar orbit with orbital planes at 45° intervals. Still another system being studied would involve what is described as a large number of satellites distributed with random phase about four different orbits at an altitude of some 6000 miles, supported by six ground stations stategically located about the globe.

Many problems remain to be solved regarding the satellite's equipment and the equipment of the would-be users. I would suggest that you look further into this problem of navigation since many progressive and useful ideas come from young scientist such as you!



Chapter V

THE RIDDLE OF MATTER AND MOTION

by

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ABOUT THIS CHAPTER

We are born and reared within the reach (the "field") of a force we call gravity. It seems to pull all masses towards the center of the Earth. Jack and Jill fell down the hill; Humpty Dumpty fell off the wall; and Darius Green crashed his flying machine. Their painful experiences added to our own, make us so familiar with the "down pulling" force of gravity that we can hardly imagine living without it. Yet, as common as it is, gravity is one of the most challenging riddles of nature. Consider, for a moment, the fact that we can block or screen out other "field forces" such as magnetism and electrostatic fields, but nothing yet known can block or even weaken the field of gravity. In aviation and the space sciences, we have been able to counter-act gravity by using jets and rockets to push or "lift" in opposition to the "pull" of gravity; but gravity is still present, even with the orbiting satellite. You will have a greater understanding of the nature of falling objects after you have read and experienced some of the problems encountered by Galileo in his long search for the secrets of gravitation.

THE TEACHER OF ALEXANDER THE GREAT

Greece — The Fourth Century B. C.

Carefully feel the difference in weight between two rocks (or coins) of considerable difference in size. Gravity is "pulling" noticeably harder on the larger one. If released, you might "logically" expect the rocks to fall with speeds related to their weights—the rock which is twice as heavy falling twice as fast. Now, drop the rocks together several times. Does the larger one always hit first or do they seem to fall together?[a] Place both rocks (or coins) in one hand and toss them a few feet to the front several times. Do you get the same results as before?[b]

Your reply should be checked each time by referring to the lettered answers in the answer section. The greatest understanding will come to those who provide their own answers before checking.

More than two thousand years ago, the Greek philosopher Aristotle (Air'-isstotle) was convinced that heavier objects should fall "quicker" than light ones. He was such a great teacher and writer that this thinking was accepted without question for over fifteen hundred years.

Figure 1. Aristotle

It was sometimes argued that when objects of different weights appear to fall together, it was only because the falling motion was too fast for accurate observation. "Certainly you can see that a stone falls faster than a feather—then why shouldn't a large stone fall faster than a small stone?" Read more about Aristotle and you will find (as is often true) that most of his teaching was more sound. But it was not put to use for almost a thousand years. It was misunderstood. During all those years written authority was accepted without careful observation and testing (experimentation).

The early Greek philosophers were amazingly close to our present understanding of the nature of matter and motion. Their knowledge was even more extraordinary in that it was acquired with "virtually no benefit of experiment or careful measurement." "The ancient philosophers thought a great deal about the WHY of phenomena, but they seldom experimented to find out the HOW or HOW MUCH." They lacked the laboratory equipment to demonstrate and to test their theories.

CHALLENGE TO THE PAST

Italy — The Sixteenth Century A. D.

In 1581 a seventeen year old Italian boy, Galileo Galei, arrived at the University of Pisa to begin the study of medicine as encouraged by his father. It soon became apparent that young Galileo's interests were more in the physical sciences than in medicine. His intense curiosity made him more interested in the events happening around him which could not be explained with existing knowledge.

A Lamp Lights the Way

It has been written that Galileo enjoyed sitting in the great cathedral, during times when few people were present, to "think out things." It was during one of these visits that he watched a "warder" light one of the oil lamps that was hanging on the wall from a chain. When the lamp was released it began to swing back and forth as a pendulum. Galileo was fascinated by the lamp's graceful motion. During this period of contemplation his acquaintance with medicine suggested the use of the heart's steady beat as a means of timing the swings of the pendulum. He reasoned that this would permit him to "see" with greater depth and clarity than the eye alone.

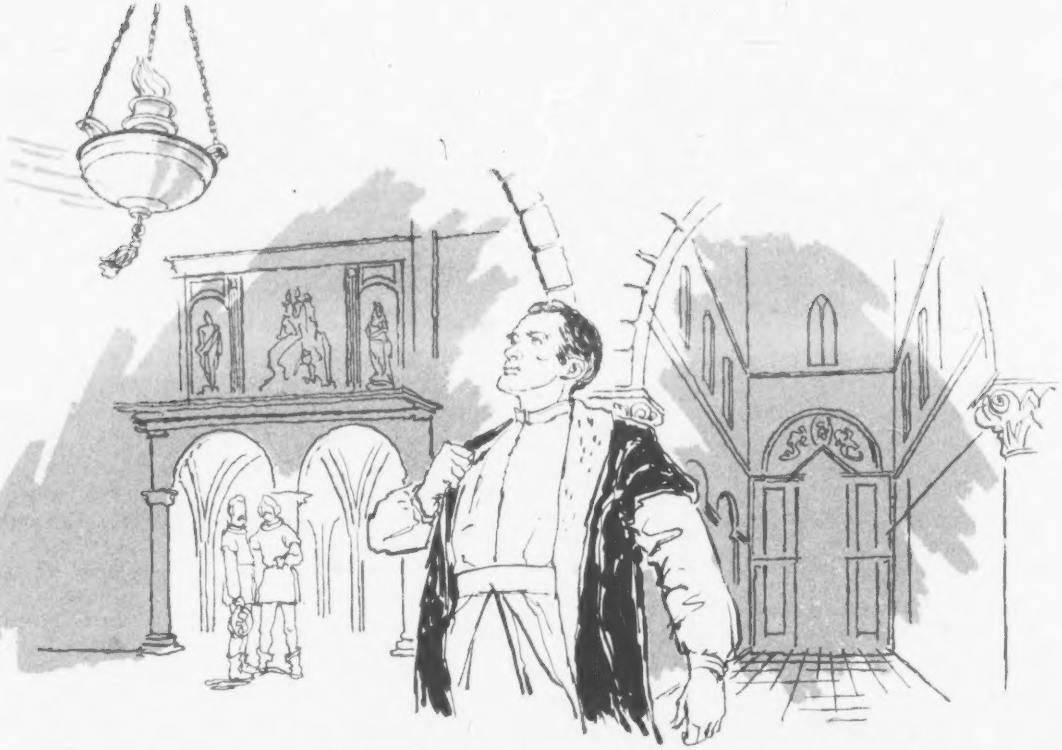

Figure 2. Galileo and the swinging lamp

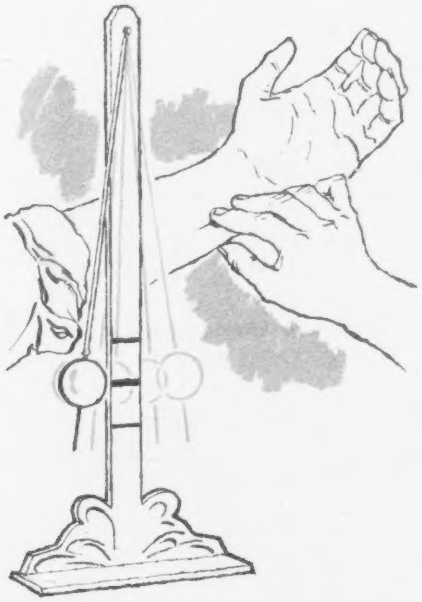

Figure 3. The Pulsilogia

Try to capture a portion of Galileo's delight by making a pendulum and using your pulse to check the time it takes to glide back and forth. The time of one "round-trip" of the pendulum "bob" is called the pendulum's PERIOD. You might use a lock or some other dense and heavy matter as a bob for your pendulum. Suspend the bob with a cord at least two meters long and the motion will be easier to observe. Get permission to drive a small nail into the top edge of a door frame, where it cannot be seen, as a support for your pendulum.

The swinging lamp observed by Galileo probably didn't swing through an arc greater than sixteen degrees and neither should your pendulum. Compute or experiment to estimate the arc distance for a two meter pendulum.[c]

Use a protractor and rule to make a scale drawing from which you can measure the arc with a string or tape measure.

How many heart beats does it take for your pendulum to swing "to-and-fro" one time?[d]

If you can't take your pulse at your wrist, you can easily feel the pulsation of the carotid arteries by gently grasping the throat just below the jaw bone.

The period can be measured much more accurately by timing it through ten consecutive periods and taking one tenth of the total time.

Galileo found a very practical use for the pendulum by blending his knowledge of medicine and physics to invent the "pulsilogia", which was simply a stick with a string and bob attached of sufficient length to swing with a period or half period equal to a normal pulse beat. The length could be adjusted for comparing slower or faster pulses by simply winding the string around the supporting hook so as to change its length. Marks were made on the stick as a scale of comparison. How do you think physicians took a patient's pulse before the pulsilogia and how do they take it today?

You might wish to use a stop watch, a clock with a second hand, or a metronome to make more accurate measurements.*

Galileo used a water clock, for further study of matter in motion. You may wish to construct a water clock similar to the plans shown below as a means of making your observation more meaningful.**

PENDULUM, RHYTHM, AND RATIO

Which of the three factors labeled on Figure 5 do you think have an effect on the period of a pendulum? Test your prediction by varying each of these factors while holding the others constant. Start by winding up the extra cord so as to have a pendulum with a 24.5-centimeter length (from *center* of bob to support). Reduce

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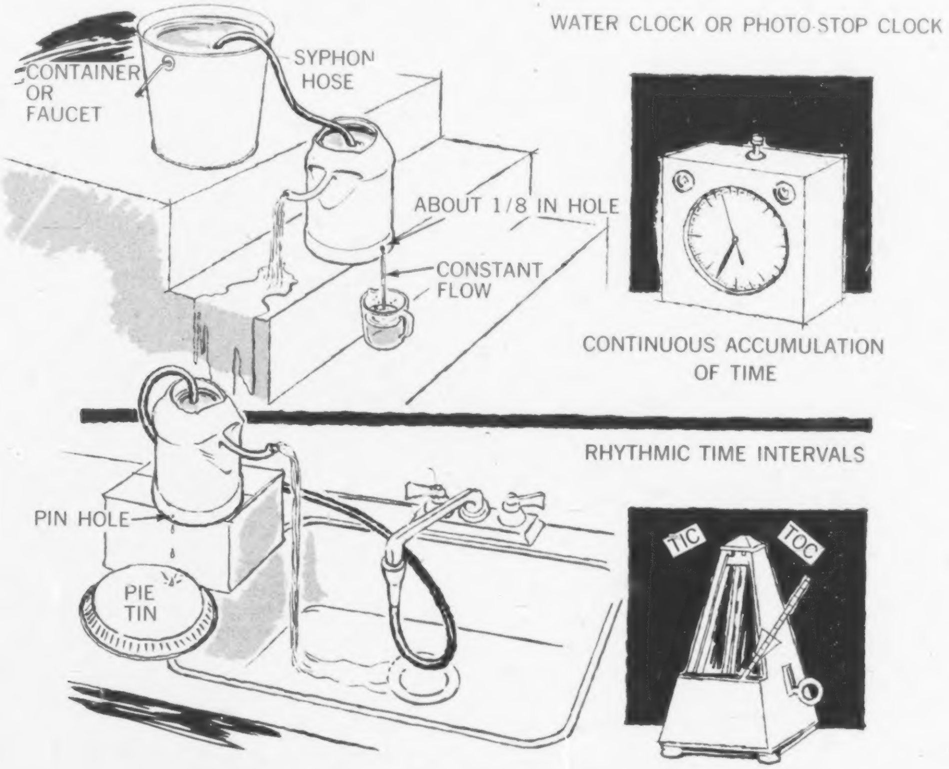
* Electronic metronomes are available which have blinking lights and audible signals.

**The handle of a gallon bleach jug is sawed off *at the top* and *forced* to bend down as a spout by folding in the plastic just beneath.



WATER CLOCK (DRIPPING) OR METRONOME

Figure 4. Rythmical time intervals and continuous accumulation of time

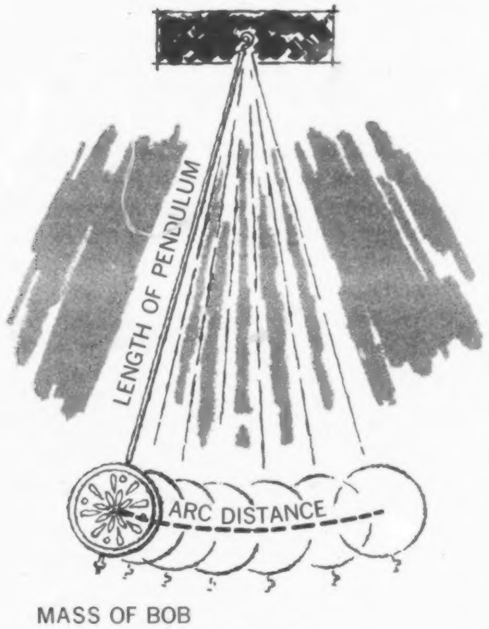


Figure 5. Pendulum

or increase your chosen variable (the arc, the mass, or the length) by using the set of "square numbers" (0, 1, 4, and 9) as factors. Make a rough graph of your results with the period (T) plotted on the horizontal axis (X axis) and the chosen variable on the vertical (or "Y") axis.[f]

Always multiply the "square number" factor by the *first value* chosen for the variable in order to get new values.

You might wish to increase the length by extending the set of square numbers on through 16, 25, and 36 *if* you can find a high enough support. (CAUTION: Request assistance from the school custodian in attaching these longer pendulums.)

What conclusion is suggested both by the effect of varying the mass of the pendulum bob and by the results observed in the rock or coin experiment performed earlier?[g]

What pattern of change do you see in the results of this experiment which indicates a "relationship" between the pendulum's Length L and period T?[h]

Gravity is the "restoring force" which causes the pendulum to accelerate after having stopped at each end of its swing. Check answers on page 20.

This relationship may be stated in the "shorthand" language of algebra as $L \propto T^2$ which reads "the length is proportional to the period squared" or reversed to $T \propto \sqrt{L}$. If either the period T or the length L change, the other must have also changed, and the amount of this change can be found by comparing the old quantities to the new by stating them as comparative fractions or RATIOS, just as you could compare three to four with the fraction ($\frac{3}{4}$).

Ratios may be equated to each other if they represent comparisons of quantities which are definitely related by a specific pattern of change, such as the obvious pattern between the length of the pendulum L and the period of swing T. Therefore, the ratio which compares the "old" length L_o to the "new" length L_n can be written L_o/L_n, and is equal to the ratio comparing the "old" period of swing T_o to the "new" period T_n, ONLY if the pattern of relative change, which was observed experimentally, is written into the equation. So, the ratio L_o/L_n *equals* the ratio T_o^2/T_n^2, or the old length is to the new length as the square of the old period is to the square of the new period. Such statements of equality between comparative fractions (ratios) are called PROPORTIONS; they are very useful in describing natural law, and as tools for finding an unknown quantity which perhaps cannot be measured directly.

The proportional relationship between changing the length of a pendulum and the changed caused in its period of swing can now be written:

$$\frac{\text{OLD LENGTH}}{\text{NEW LENGTH}} = \frac{\text{OLD PERIOD}^2}{\text{NEW PERIOD}^2}$$

$$\text{or} \quad \frac{L_o}{L_n} = \frac{T_o^2}{T_n^2}$$

If any one of the four quantities is unknown while three are known, the unknown can be found by "solving the equation" algebraically.

Use the above equation to find the length (L_n) a pendulum should be for a "grandfather" clock in which the one way swing from "tic" to "toc" takes exactly one second. Such a pendulum is called a "seconds pendulum". Remember that from "tic" to "toc" is only a half cycle; therefore, one second is only one half the pendulum's period (T_n).* Use the length and period from one of the pendulums which you think was accurately timed in the previous activity as a "standard" to represent the "old" length (L_o) and period (T_o) factors in the equation.[i] (The new period T_n is 2 seconds).

Supplemental Problems

Use the proportional relationship between a pendulum's length and its period to solve the following problems (let the "seconds pendulum" of the last exercise serve as your "standard" for stating new ratios):

1. What will the period be for a pendulum of 3.92 meters length?
2. Colorado's Royal Gorge bridge could suspend a pendulum with a 35 second period. How deep must the Royal Gorge be?
3. What would be the theoretical period of a one mile pendulum?
4. Is there a vertical drop anywhere on earth where pendulum could be suspended so as to have a period of about one minute?
5. In 1851 the French physicist Jean Foucault (Foo-Koh') demonstrated that the earth rotates by suspending a large iron ball on a wire about 200 feet long with a "free swiveling" hook. The pendulum continued to swing, in one direction with respect to space, as the floor beneath it turned hour by hour with the Earths' rotation. What was the period of Foucault's pendulum?

Figure 6. Angel Falls

THE LEANING TOWER OF PISA

Galileo's pendulum indicated that heavier objects do not fall faster, as most people had believed for almost two thousand years; but many would not accept the "falling" of the pendulum bob as being directly related to the free fall of unrestrained matter. The story is told that in order to settle this argument Galileo staged a public demonstration in which he dropped a musket ball and a cannon ball, of about one pound and one hundred pounds respectively, from the famed Leaning Tower of Pisa. There is no record of this demonstration; but such records may have been destroyed, because the idea of "equal fall" was very unpopular with the ruling powers as it challenged the established and officially recognized order of nature. It *is* recorded that a pro-Aristotelian scholar used the Leaning Tower during Galileo's lifetime to demonstrate *unequal* fall. This demonstration was probably performed with one ball of solid iron and the other of wood or sheet metal. What role would air have in such an experiment; and why wouldn't it have influenced Galileo's two solid metal balls to the same extent?[j]

*** In 1657 the Dutch astronomer, Huygens (Hi'-gunz) used Galileo's discovery to produce accurate, pendulum-regulated clocks.**

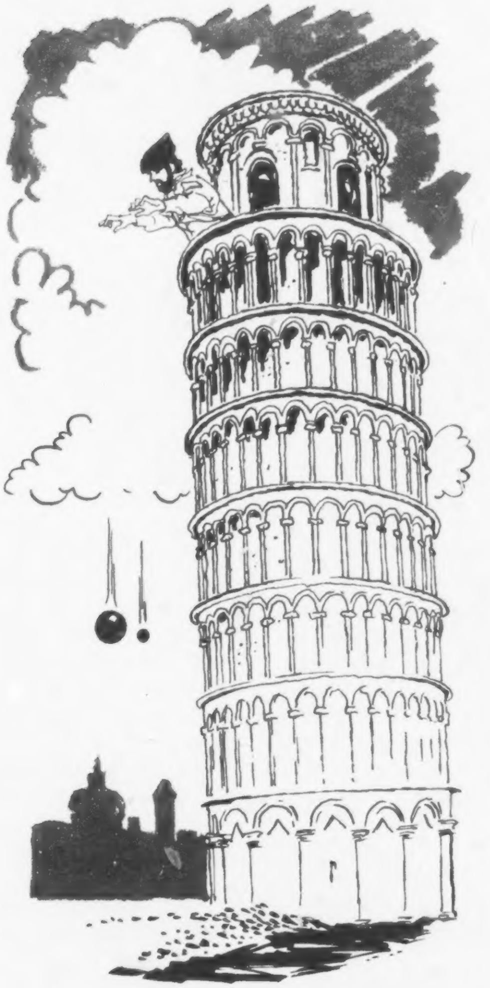


Figure 7. Leaning Tower of Pisa

Drop a coin and a dollar bill, or a stone and a piece of paper, at the same time. Now, tightly fold the dollar bill or paper in half five or six times and drop them again.[k] In falling great distances through air the more dense objects would eventually gain greater velocities than the folded paper, due to their greater ability to shove through the air as it compresses in front of them at the greater speed attained in long falls. The same factor (frictional drag due to air resistance) would have caused the wooden ball to fall behind the iron ball when dropped from the Leaning Tower.

You may perform the previous experiment with a large coin and a small piece of paper, preventing air drag on the paper by laying it flat (no corners sticking up) on top of the coin.[*] This same frictional restraint of the air "rubs" the heat shield of returning space vehicles and the surfaces of meteors until they reach the incandescent temperatures which cause their fiery entry into the Earth's atmosphere. Air resistance permits the parachutist to glide to earth at about 15 mi./hr. (22 ft./sec.) rather than the nearly 120 mi./hr. velocity attained by a "free falling" man. Sharpen your skill in using proportional ratios by calculating the velocity in feet per second attained by a falling "sky diver" using the three velocity values of the last sentence as your three known factors.[l]

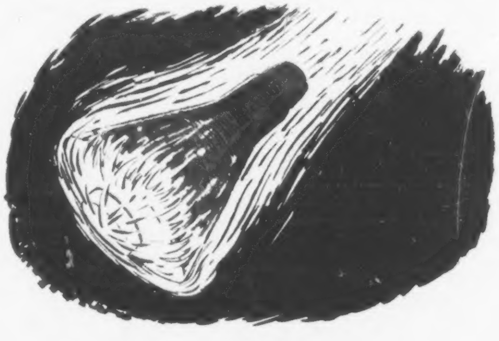


Figure 8. Re-entry

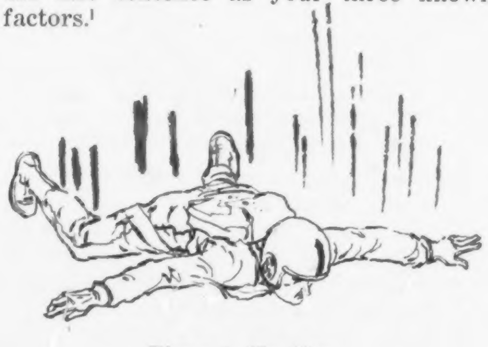


Figure 9. Sky-diver

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[*] A "feather and guinea tube" will permit one to observe the free fall of a feather and a coin in the absence of air.

LEANING TOWER ACTIVITY

You may not have a leaning tower from which to demonstrate "equal fall", but you probably can get permission from the principal to use the school flagpole if the project is to be supervised by a teacher.* You are more likely to be given permission if:

A. You have proven yourself to be a responsible student in the past.

B. You explain that *no one* will be climbing the pole.

C. You make it clear that only *SOFT* objects which weigh less than three pounds will be hoisted up the pole.

If permission is granted then proceed as follows:

1. Prepare a paper carton of the type used for canned goods (about 7"×14"×18") as shown in Figure 10.
2. Secure three or four heavy canvas bags of about one quart capacity. The change bags used by banks and retail stores are ideal and sometimes are given away when soiled or you can purchase canvas or ticking and make them. Put about one pint of sand in one of the bags and dry beans in another. Close the tops securely but allow plenty of room inside to prevent splitting upon impact.
3. Attach the box to the flagpole chain with a cord tied from the broom stick to the chain at the lower end.
4. Attach the top of the box by pulling the chain *down* through the slit cut in the upper end; and placing a long pencil or thin brittle stick through the loop, just under the top edge, to prevent the chain from pulling out.
5. Tie a steel measuring tape to the chain, just below the box; and hoist the chain high enough to tie a handkerchief, as a marker, at one or both points shown in the drawing depending on the pole's height.
6. Load the bags of sand and beans and hoist them *steadily* to the top (without jerking). The bags may be dumped together by a gentle tug on the chain which releases the top of the box.
7. Repeat the demonstration several times and try to verify the time of fall to the markers with the aid of a "seconds pendulum". You could have an assistant sound out the rhythm of the seconds pendulum with a snare drum.[m]

Calculate the *average* speed of the falling bags up to the time of impact.* A stop watch, or your water clock, may be used to measure the time factor. How can you determine the distance fallen by measuring the shadows of the flagpole and a vertical yard stick?[n]

By comparing the distances fallen during the first and second intervals, it is apparent that the speed of fall is increasing (or ACCELERATING). The rate of this "speeding up," however, is not so apparent, except for the clues given by the location of the handkerchief, as shown in the drawing. After one second of falling the bags have moved 16 feet; so their *average* speed was 16 feet per second during the 1st second of fall. What "instantaneous" speed did the bags have at the *start* of the 1st second? ** It seems logical to think—since the speed "averaged out" at 16 feet per second during the whole 1st second, from a beginning speed of zero feet per second—that the final speed should be as much greater than 16, as 16 is greater than zero; or 32 feet per second. Notice that the bags fell (48 minus 16) or 32 feet further during the 2nd second than during the 1st—this also suggests that the speed is increasing 32 feet per second for each second of falling—as it did during the 1st second in going from zero feet per second

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* If you happen to live near Niles, Illinois, you might arrange a trip to the "Leaning Tower of Niles" for your reenactment of Galileo's demonstration. The tower at Niles is a good replica of the Pisa tower and is open to the public free of charge. It was built as a water tower in 1920 and is about the height of a ten-story building while the tower of Pisa stands twice as high.

**It is often considered best to use the word velocity rather than speed when referring to speed in a particular direction; however, where brevity is essential to understanding, the one-syllable word seems the better choice.

† At the *very beginning* of the first second the bags were not moving at all; so their speed *at that instant* would be . . .

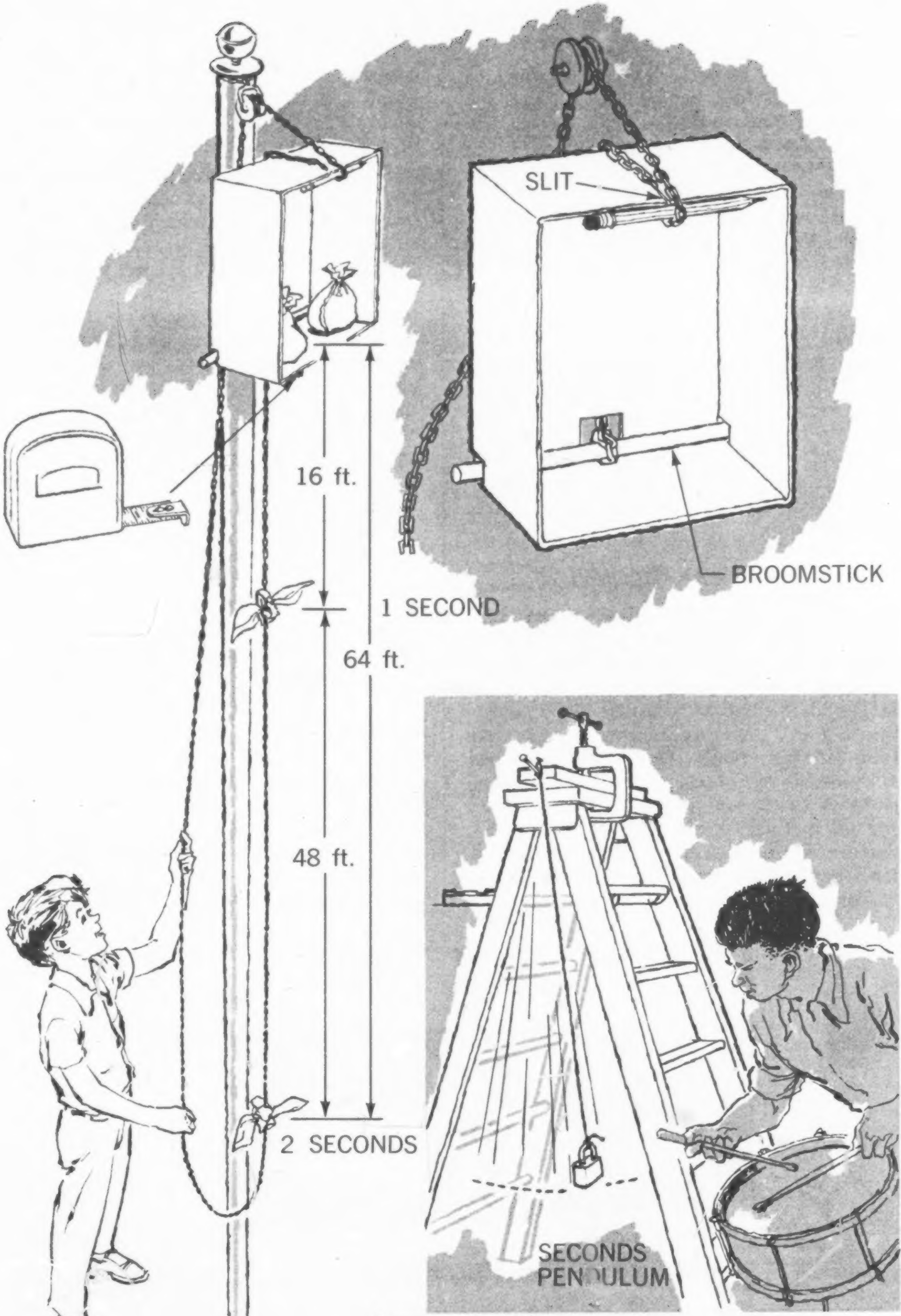
SLIT
BROOMSTICK
16 ft.
1 SECOND
64 ft.
48 ft.
2 SECONDS
SECONDS PENDULUM

Figure 10. Free fall

See page 95 for a related free-fall activity to 32 feet per second. The speed, then, is changing 32 feet per second during the passing of each second of time. Thus, the *rate of change of speed* (or ACCELERATION)is 32 feet per second *per second.* This same acceleration may be abbreviated as 32 ft./sec.–sec. or 32 ft./sec.^2 A small letter "a" is usually used as a symbol for acceleration; however, when the acceleration is caused by gravity it is customary to use the letter 'g"; so, in this example $g = 32\ \text{ft./sec.}^2$

6. How far should the bags fall during the third second *if* the acceleration remains constant? (assume the pole to be high enough to permit this)
7. At what distance should the third handkerchief be from the box to mark the limit of fall after three seconds?

"DILUTED GRAVITY"

You have surely observed, just as Galileo did, that the motion of free-falling bodies is too fast for detailed study. Galileo reasoned that the rapid motion of a free-falling ball could be restrained by allowing it to roll down an inclined plane. The time of fall would then be lenghtened ("diluted") by a factor.proportional to the slope of the grooved board which he used for an inclined plane. Even though side factors, such as friction, prevented Galileo from discovering the actual amount of increase in velocity (or acceleration) caused by the pull of gravity; he was successful in making a great discovery concerning the relationship between the time of fall and the distance fallen.

With a little patience, you should be able to repeat a form of Galileo's "diluted gravity" experiment which may enable you to observe the orderly relation between the time an object falls and the distance it falls. Galileo, in his relentless quest for knowledge, required years of study and hours of *patient repetition* of experiments in order to eventually see through the clouds of side effects and uneven measurements which usually guard nature's secrets. In the interest of simplicity and of saving time, you may find it convenient to use the following "set-up" for this experiment:

The inclined plane should be a good straight board about six or eight inches wide. Position books under the board so as to raise one end exactly three inches above the floor at a distance of six feet from the other end. Compare the height of the inclined plane with its length by stating it as a ratio.[o] How do you think gravitational acceleration (or "g") will be affected by this set up?[p]

Use a glass jar or bottle with either straight or concave sides filled with a fairly dense material such as crushed stone, sand, or water. The jar or bottle must have exactly the same diameter at both the shoulder and the base if it is to roll true.

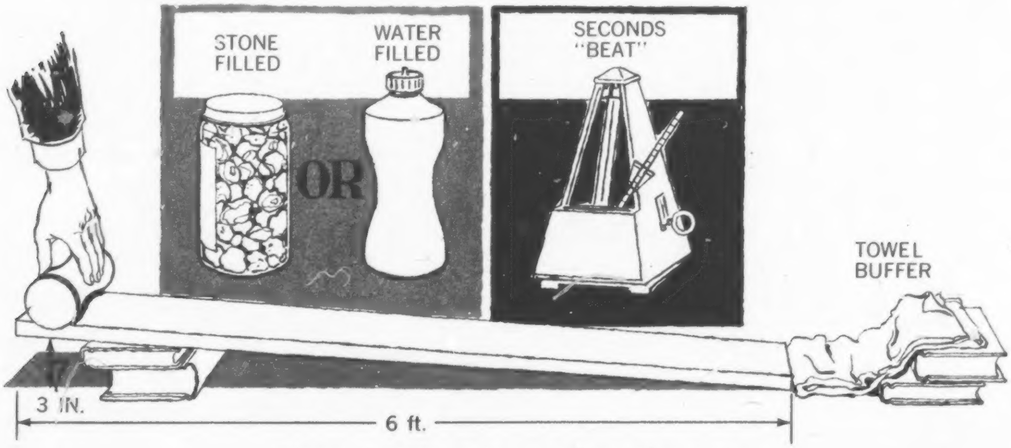

Figure 11. Inclined plane used to study gravity

Practice releasing the jar at the starting line, by lifting your hand straight up (without pushing) until you can release it right on the seconds beat of an audible timing device (metronone or dripping water). Position four alert assistants along the board, with chalk in hand, ready to mark the position of the jar after the first, second, third, and fourth seconds respectively. Repeat the operation four times, rotating the positions of the assistants, so as to have a set of four marks at each position, which can be roughly averaged out with single marks. Measure and tabulate the distances from the starting line to each mark.[q] Can you detect a pattern suggesting a relationship between the distance rolled during the first second and the other distances?[r]

Try dividing the distance traveled in one second into the distances traveled in two, three, and four sconds. Compare the results.

Make a graph with the time plotted on the x axis and the distance on the y axis.[s] Compare this graph to graph "f" of the relationship between the pendulum's length and period. They should have about the same shape—a parabolic curve—which shows not only that the distance factor *increases* with the time factor, but that this increase is greater than the corresponding increase in the time factor. It is an *accelerated* increase caused by the "pull" of gravity.

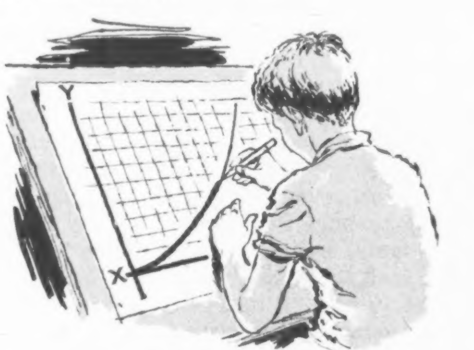

Figure 12. Student preparing graph

From an analysis of his inclined plane experiment, Galileo was able to announce —*that the distance an object falls is directly proportional to the square of the elapsed time* (or $s \propto t^2$).

Refer to the tabulation of data obtained from the inclined plane activity (item "q" in the answer section). The distances in the table are cumulative from the instant the jar or bottle started to roll. What were the distances traveled in *each* of the four seconds?[t] Of course, "the distance traveled in each second", asked for in the last question, is the average speed or velocity during that particular second. How much does the average velocity increase from one second to the next?[u] This increase of velocity from one time interval to the next is called acceleration; so the answer to question "u" is the acceleration in inches per second *per second* (or in/sec.^{2}) for the rolling jar or bottle. Notice that the acceleration from one second to the next is always the same. From this observation, Galileo was able to announce a second major principle concerning gravity—*that the acceleration of a falling body is constant.* He had demonstrated with the inclined plane that the acceleration was constant for a rolling ball; and he reasoned, correctly, that free-fall was similar to the motion of a ball on a very steep and smooth plane.

ACCELERATION IS A CHANGE IN VELOCITY

The acceleration, (change in rate of motion) which the force of gravity exerts on an object here on the Earth's surface is such a common experience that we often use it to describe accelerations due to other forces. We speak of booster rockets accelerating at so many "g's" causing the astronauts and equipment to experience a crushing "pull", many times that of gravity alone, as the booster presses upward against them. You may experience a similar sensation, to a small degree, when riding in an elevator.

There is no record of Galileo having determined the actual value of g, the downward acceleration due to the Earth's gravity. However, he certainly set the stage for its later discovery, with the development of better equipment and procedures for experimentation. Today "g", the acceleration due to gravity, is measured di-

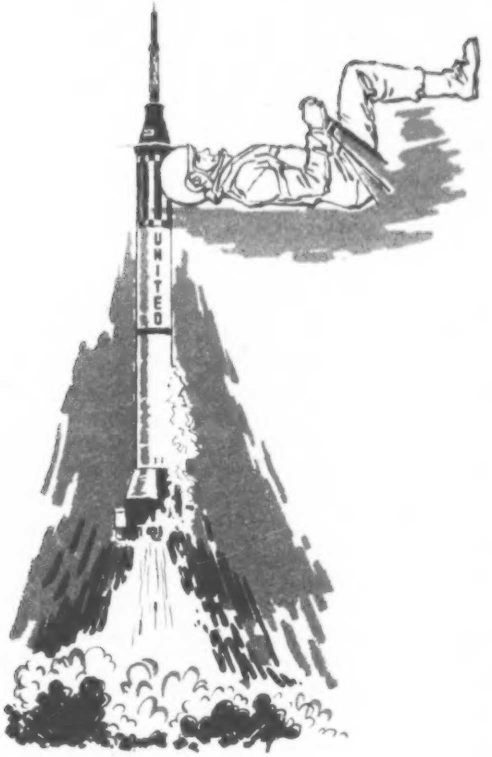

Figure 13. Astronaut in seat during launch

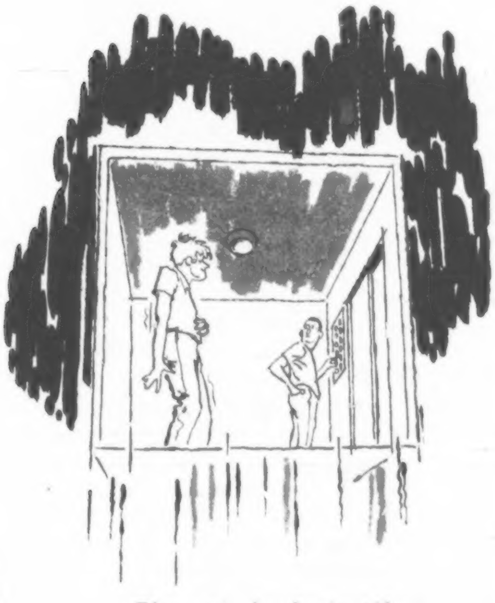

Figure 14. An elevator ride

rectly by scientists in the National Bureau of Standards by accurately timing the free-fall of a quartz rod.

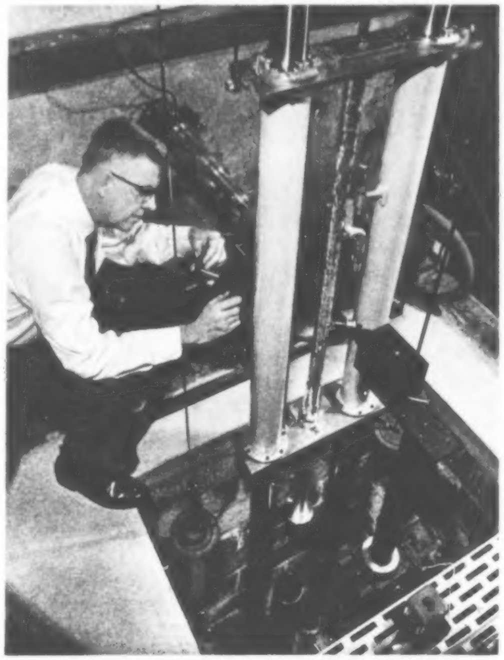

Figure 15. Measurement of acceleration of gravity

Photograph courtesy of The National Bureau of Standards, United States Department of Commerce.

Since gravity is the "restoring" force which causes a pendulum to vibrate, any change in the downward pull of gravity causes a change in the pendulum's period; and so, pendulums have been the standard means of measuring g for years. If g is greater the pendulum bob "falls" faster; therefore, its period is shorter. Portable "gravimeters" are used by oil prospectors which measure g by the amount a delicate spring or fibre is stretched by the weight of a metal bob. Such instruments have been used to make gravity surveys of different regions which have shown that g is not exactly the same at all places on Earth. The difference in the measure of g has presented a problem in determining world records for athletic events: a broad jumper in Canada falls a little faster toward the ground than a jumper in Mexico at the same elevation, because g is a little greater as you approach the poles of the Earth.

Figure 16. Broad jumper

MEASURING "g"

The following activity will enable you to make a rough measurement of g for your locality. The activity is based directly on the principle of the pendulum as developed by Galileo and is, in fact, a simple (but ingenious) combination of a pendulum and a free-falling metal ball.* The fall of the metal ball is intercepted by a wood strip about 120 cm. long, swinging from a loosely fitting nail as shown in figure 17.

The pendulum's period is first found by using a clock to time a series of swings (at least 30 periods). A single thread is fastened to the ball and passed over two nails and down to the strip so as to hold it aside as shown. Hold the ball away from the board and thoroughly blacken it with a candle. The candle may then be used to burn the thread so as to release both the ball and the pendulum simultaneously. The blackened ball will mark the strip at the point of impact so that the distance fallen by the ball, in one quarter of the pendulum's period, can be measured directly. The acceleration due to gravity can then be calculated with Galileo's formula for constantly accelerated motion:

$s = \frac{1}{2}\, a\, t^2$ or for free fall: $s = \frac{1}{2}\, g\, t^2$

where s is the distance fallen as measured and t is the time of fall (or one-fourth the strip's period).

PROJECTION

In 1642, the year of Galileo's death in Italy, Isaac Newton was born in England and was destined to continue the search which led eventually to his discovery of

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* Variations of this activity are found in several physics' texts and the *UNESCO Source Book for Science Teaching*, p. 125.

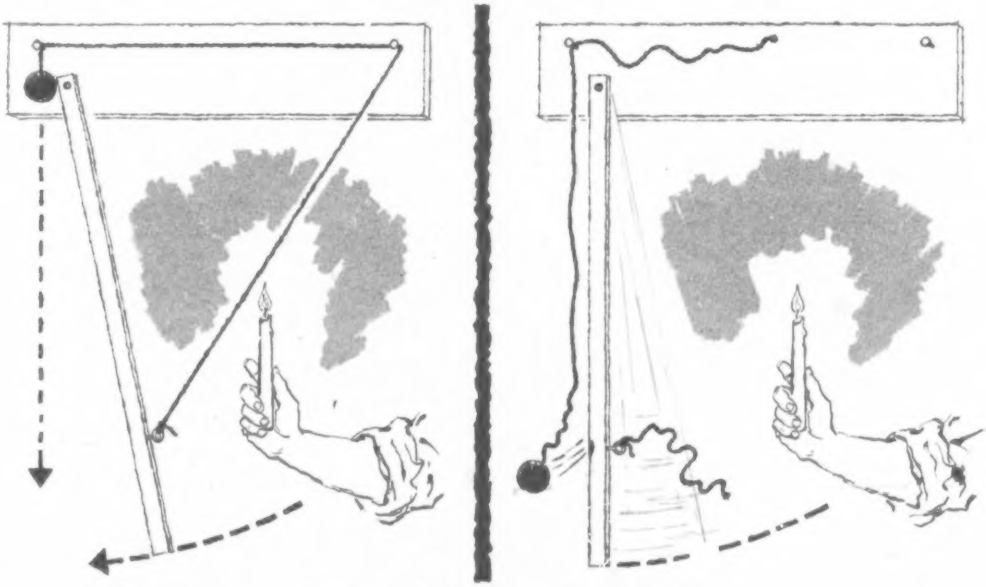
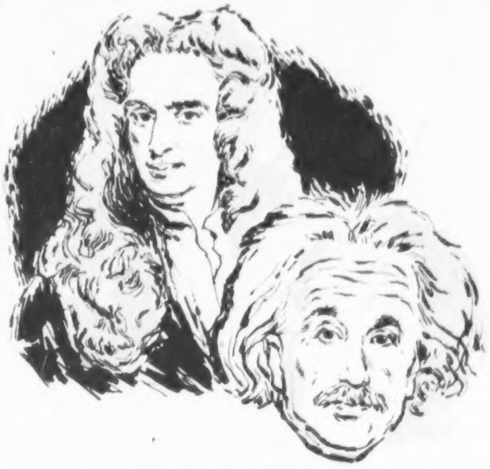


Figure 17. Apparatus for measuring "g"

the universal law of gravitation. Newton surely must have had Galileo in mind when he protested to those who would idolize him: "If I have seen farther than others, it is by standing on the shoulders of giants."

Each great discovery concerning gravity has revealed new riddles along with understanding. In this century the German-American scientist and mathematician, Albert Einstein, has modified Newton's statement of the nature of gravitation with his "theory of general relativity" and has questioned the very existence of a "force of gravity" as being necessary to cause the acceleration of falling objects. His "principle of equivalence" states that no observation or measurement can distinguish between the effects due to gravity and those which would be caused by the accelerated movement of the observer's surroundings.

Visit your school or city library and find some of the books that are listed in the bibliography. You will find them very interesting and the time invested in them will greatly increase your understanding of gravity and motion.



NEWTON $F = G\frac{M_1 M_2}{d^2}$ / *EINSTEIN* $E = mc^2$

ESSENTIAL TOOLS

A Supplemental Activity

A FORMULA is a short hand device useful in solving a problem. It is an abbreviated statement of a natural law as observed and carefully tested by scientists and mathematicians.

Take a string and wind it one time around a jar lid or coin to form a circle. Cut the string at the point of overlap and straighten this "circumference" to form a straight line. Now, stretch this "circumferential" string back and forth across the diameter of the lid or coin as many times as it will reach. How many diameters are in the circumference? Repeat the process with a coin or lid of a different size? *

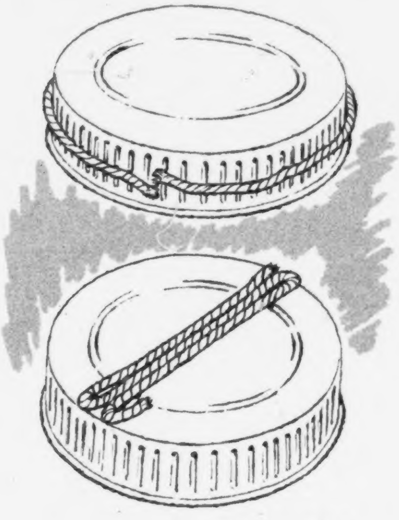


Figure 20. String and lid

You have been comparing diameters with circumferences by *dividing* the circumference c by the diameter d. Such a comparision by division may be written in any of the following ways: $d\overline{)c}$, $c \div d$, *or* c/d; which are simply three ways of writing in symbols "How many times does the diameter fit into the circumference." A comparison of two quantities by division is called a ratio. Ratios are usually written as fractions such as c/d; of course, the fraction may be changed into decimal form by performing the division.

With the string and coin, you have seen that the circumference is always about 3 and 1/7 times as long as the diameter, regardless of the circle's size. The ratio is approximately 3 1/7, 22/7, or 3.14^+ and is called a "*constant*" because the ratio of the circumference to the diameter never changes. This particular constant is used so often that it has been labeled with the Greek letter π (pi). We define π as the ratio c/d.

Thus, the natural law concerning the relationship between a circle's diameter and its circumference can be written as a formula: $c/d = \pi$, *or* $c = \pi \times d$, *or* $d = c/\pi$. If either c or d is unknown, or not easily measured directly, it can be approximated by algebraic solution of the equation made by simply substituting numbers for the symbols in the formula. Use the ratio "π" to approximate the following:

8. How far does the Earth travel along its nearly circular orbit in one year? The mean distance from the sun to the Earth is about 93 million miles. Use 3.14 for your approximation of π.
9. What is the approximate thickness of an oak tree whose "girth" is ten feet? Use 22/7 for an approximation of π.

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* You are not breathing deeply of life unless you can enjoy such simple demonstrations of truth.

A RELATED FREE-FALL ACTIVITY

Potatoes or blocks are fastened to a light rope at intervals of 16 units, 48 units, 80 units, etc. and then the rope is hoisted vertically with the greatest interval being farthest from the ground. An old washtub is placed beneath the rope as a sounding board. When the rope is released, the potatoes or blocks fall with constantly accelerating 21 velocities so as to arrive at the tub in rhythmatic order. If the units selected are feet, of course, the potatoes impact on the second. (adapted from Sutton's *Demonstration Experiments in Physics*)

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Chapter VI

THE MEASURE OF SPACE

by
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ABOUT THIS CHAPTER

"*Astronomy compels us to look upwards and leads us from one world to another.*"—Plato

Until a few centuries ago man knew only one world, the planet on which he lived. From this small world, which is measured in numbers well within our understanding, we look to the sky in the search for more knowledge. Until the first telescope was used by Galileo in the sixteenth century, man thought that the Earth on which he lived was so important that everything in the sky revolved around it. With the use of the telescope, Galileo soon realized that Copernicus was correct when he said that everything revolved about the sun. This was unbelievable to the people of that time. With advances in astronomy, the sun and its solar system, of which the Earth is a part, were found to be a part of a huge galaxy. When still other galaxies were discovered, the Earth seemed smaller.

You have already been taught to understand things in terms of measurement; by describing the beginning and the ending point of the object in question. But are you able to conceive something having no beginning or ending points? Can we know the boundaries of something the measure of which we cannot even begin to describe? Unlike men of centuries past, we are now able to explore and venture into the space around us. But, with every question answered, more questions arise.

AN EASY CONVERSION PROCESS

Many times, even in your daily activities, you are required to change the units of a measurement to units of another. It may be as simple as finding the number of eggs in a given quantity of dozens, or changing feet per second to miles per hour. The key thought is knowing and remembering the units you are given and the units you need to find.

In your mathematics class you have learned that multiplying a quantity by one does not change its value. There are quantities which can be substituted for one. The following are a few of them.

$$\frac{1 \text{ dozen}}{12} = 1 \text{ or } \frac{12}{1 \text{ dozen}} = 1$$

$$\frac{5{,}280 \text{ feet}}{1 \text{ mile}} = 1 \text{ or } \frac{1 \text{ mile}}{5{,}280 \text{ feet}} = 1$$

$$\frac{60 \text{ seconds}}{1 \text{ minute}} = 1 \text{ or } \frac{1 \text{ minute}}{60 \text{ seconds}} = 1$$

$$\frac{2.54 \text{ centimeters}}{1 \text{ inch}} = 1 \text{ or } \frac{1 \text{ inch}}{2.54 \text{ centimeters}}$$

The above unities and others are the bases for conversion from unit to another.

If you wanted to find the number of hours in one week, do you know whether you should multiply or divide? Follow the example below to see if you were correct in your choice.

$1 \text{ week} \times \frac{7 \text{ days}}{1 \text{ week}} \times \frac{24 \text{ hours}}{1 \text{ day}}$. The week and day units can be eliminated by "cancellation" leaving only the desired unit. Think of the expression as:

$$\frac{1 \text{ week} \times 7 \text{ days} \times 24 \text{ hours}}{1 \text{ week} \times 1 \text{ day}},$$

Dividing by 1 week yields:

$$\frac{1 \times 7 \text{ days} \times 24 \text{ hours}}{1 \quad \times 1 \text{ day}}$$

Dividing by 1 day yields:

$$\frac{1 \times 7 \times 24 \text{ hours}}{1 \times 1}$$

Having taken care of the units, the required calculations are clearly shown. In this particular case the calculations would be 1 × 7 × 24 hours = 168 hours.

The above example was quite easy, so try the more difficult following example. Calculate the number of centimeters in 0.5 mile. (Hint—remove the denominators by dividing first by 1 mile then by 1 kilometer.) $0.5 \text{ mile} \times \frac{1.61 \text{ kilometers}}{1 \text{ mile}} \times \frac{100{,}000 \text{ centimeters}}{1 \text{ kilometer}}$. Again the mile and kilometer units are conveniently eliminated leaving only the desired centimeter unit. The calculations are as follows: $0.5 \times 1.61 \times 100{,}000$ centimeters = 80,500 centimeters.

A still more difficult conversion might be that of changing the units for a rate of motion. Suppose an European journal publishes an article stating that a sizable meteor falling through our atmosphere had a speed of 50 kilometers per second. For you to best understand this speed you would probably have to change it to miles per hour. This is done in the following way:

$$\frac{50 \text{ kilometers}}{1 \text{ second}} \times \frac{3{,}600 \text{ seconds}}{1 \text{ hour}} \times \frac{1 \text{ mile}}{1.61 \text{ kilometers}}.$$

Which units remain when you "cancel"? By following through with the calculations you should get a speed of 111,801.2 miles per hour.

You and your friends can think up several more of these conversions before going farther with this booklet. After a little practice you will find it easier to work the problems by setting them up in the above mentioned way when possible. Try different methods. Find one that you understand then use it for converting from one system to another.

DISTANCES

If the distance from the Earth to our moon at this moment is 238,857 miles, are you able to calculate the distance in kilometers? How long would it take a satellite to travel from the Earth to the planet Venus if the velocity of this satellite is 10 kilometers per second and it must travel a distance of 64,800,000 kilometers? What would be the velocity of a satellite in miles per minute if its circular orbit was 28,260

Figure 1. Satellite distance

miles long and it revolved around the Earth every 118 minutes?

All three questions mentioned above are concerned with measuring one of several quantities. The scientist, as well as yourself, is concerned with measurement. Both you and the scientist then use the measurements to describe what is present or what is happening at a particular time and place. (List several quantities that you and a space scientist might wish to measure.)

Before we can speak of velocity and acceleration, we should first be concerned with the distance between two given points. Even though there are many units which can be used to describe a certain distance, we will be mainly concerned with the metric system of measurement. Knowing the prefixes to the most common metric units can be a great help to you. The meanings are as follows: kilo = one thousand (1,000); centi = one-hundredth (0.01); and milli = one-thousandth (0.001). Table 1 shows metric equivalents with the abreviations. The meter is the basic unit. Table 2 shows metric and English equivalents. Complete tables 1 and 2. Think: Why do you not need to complete the darkened spaces?

Many countries on the Earth are using the metric system. So until the United States adopts this system of measurement, you will need to be able to convert distances from one system of measurement to the other.

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Problems: Refer back to your completed tables. Remember the meaning of *kilo*, *centi*, and *milli*)

1. The zodiacal light is believed to be caused by sunlight reflected by a ring of small dust particles around the sun. If these dust particles range in size from 0.001 to 1 millimeter in diameter, what is this range of size in (a) centimeters, and (b) inches?
2. The passive Echo II satellite has a satelloon skin 0.0007 of an inch thick, which is only a fraction as thick as a human hair. What is this thickness in (a) centimeters, and (b) millimeters?
3. If the diameter of the nucleus of a comet is 1.4 kilometers, what is this diameter in (a) meters, (b) feet, and (c) miles?
4. TIROS I (Television InfraRed Observation Satellite) transmitted weather information to receivers on the Earth from an orbital range of 428.7 to 465.9 miles above the Earth's surface. What was this distance range in (a) kilometers, and (b) meters?
5. Echo II is a passive satellite that reflects radiowaves sent to it instead of receiving and transmitting as an active-repeater satellite relays information. Echo II has a diameter of 135 feet. What is this diameter in meters?
6. (a) If the diameter of dwarf stars is generally between ½ and 4 times the

TABLE 1.—Metric equivalents

	Kilometer	Meter	Centimeter	Millimeter
1 Kilometer km	▨	1000	100,000	
1 Meter m	0.001	▨		1000
1 Centimeter cm		0.01	▨	10
1 Millimeter mm	0.000001		0.1	▨

TABLE 2.—English-metric equivalents

English to metric	
1 Inch	25.40 Millimeters mm
	Centimeters cm
	0.0254 Meter m
1 Foot	300 Millimeters mm
	Centimeters cm
	0.30 Meter m
1 Mile	Meters m
	1.61 Kilometers km

Metric to English	
1 Millimeter mm	0.039 Inches in
1 Centimeter cm	Inch in
	0.033 Foot ft
1 Meter m	Inches in
	3.28 Feet ft
	Mile mi
1 Kilometer km	3280 Feet ft
	0.62 Mile mi

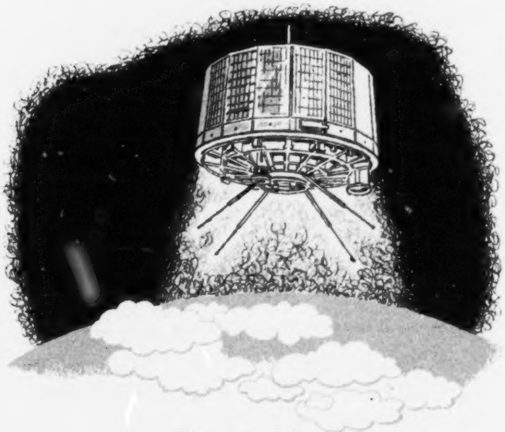

Figure 2. Tiros I

Earth's diameter (7,913 miles), what is their range of sizes in kilometers?

(b) The visible diameter of the sun is 864,000 miles. What is the visible diameter of the sun in kilometers?

(c) Betelgeuse (bēētle-juice), a supergiant star, has a diameter about 450 times the diameter of the sun. What is the diameter of Betelgeuse in kilometers?

7. The Earth's magnetic field blends with the interplanetary magnetic field at about 100,000 kilometers above the Earth's surface. What is this distance in miles?

and (x) is the x-coordinate, the focal point (f) can easily be found. Figure 6 shows what is meant by the above terms, and how a parabola differs from a sphere.

In figure 6, assume the focal length of the parabolic mirror to be three. You can then assign a value to (y), square it, and solve for (x). These numbers are then plotted on the x- and y-coordinates.

……

Problems:

14. The 200-inch mirror of the Hale telescope is coated with a very thin molecular layer of aluminum which serves as the reflecting surface. Find the focal length in feet and in meters of this telescope if x = 0.9 feet when y = 10.0 feet.
15. Find the focal length of a parabolic mirror in a do-it-yourself telescope if x = 0.5 inch when y = 6 inches. What is the focal length in centimeters?

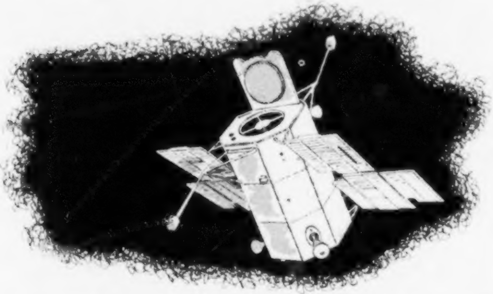

Figure 7. Orbiting Astronomical Observatory

16. The planned orbiting astronomical observatory (OAO) will have a parabolic mirror 0.9 meter in diameter. Find the focal length of this mirror if x = 1.38 meters when y = 4 meters. Graph the parabolic cross-section as was done in figure 6.

……

Occasionally astronomers find an object with a parabolic orbit passing through our solar system. Most of these objects are comets which expel gas particles due to the sun's heat. These gas particles reflect sunlight as they pass near the sun, much as dust floating in a beam of light. For this reason we are able to observe them. If an object has a parabolic orbit with the sun at the focal point of the orbit, it means that it is traveling with a speed in excess of 616 kilometers per second. The velocity of an object with a parabolic orbit passing close to the sun but not drawn into the sun will carry it so far beyond our solar system it will never return.

……

Problems:

17. What is the above velocity (escape velocity) of the object in (a) miles per second, (b) kilometers per hour, and (c) miles per hour?
18. A comet with a parabolic orbit passed within 7 million kilometers of the sun (focal length of the parabola). Construct a small table of values for the x- and y-coordinates and draw a graph showing the curve of the comet's orbit.

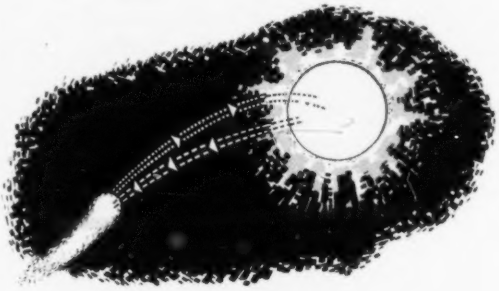

Figure 8. A near collision

19. One of the many theories of the origin of the solar system is a near collision between the sun and another star. This star would no doubt have had a velocity great enough to give it a parabolic orbit, as it approached the sun, and it might have passed within a range of 1 million to 100 million miles of the sun. Draw the graphs of the two parabolas for a comparison of the two using a convenient scale.

……

Objects traveling with a velocity great enough to give them a parabolic orbit are the exception rather than the rule. If the velocity of an object were to slow down to the point where it would repeat the same orbit around the sun, it would have a long period of revolution (many hundreds of years) and its orbit would be termed as near-parabolic. If the slowing down process were to continue, the object would revolve around its primary, such as our sun, in a much shorter period of time and its orbit would be termed an ellipse.

The planets all have elliptical orbits as do their satellites, and their average distances from the sun are measured in astronomical units. An astronomical unit is equal to about 93 million-miles (usually given as 92,870,000 miles), which is the Earth's average distance from the sun.

20. How many kilometers are equal to one astronomical unit?

TABLE 3.—Bode's rule

Object from sun	1st	2nd	3rd	4th			7th	8th	9th	10th
Double each succeeding no.	0	3	6	12					—	
Add 4 to each column	4			4					—	4
Total each column	4			16					—	
Divide each Number by 10	.4			1.6						
Actual mean distance from sun (A.U.)	0.38	0.72	1.00	1.52	2.77	5.20	9.54	19.18	30.60	39.52
Planet name	Mercury	Venus	Earth	Mars		Jupiter	Saturn	?	?	?

Bode's "Rule"

Near the end of the eighteenth century a German astronomer, Bode, noted that there seemed to be some degree of regularity in the distances of the planets from the sun. Bode was able to construct a table showing the distances of the planets from the sun in astronomical units. To do this, Bode started with the number 0 followed by the number 3. After this step the number 3 is doubled (6) which in turn is doubled (12) and so on. You may use table 3 to perform the same calculations which Bode performed.

The next step in Bode's calculations, and now yours, is to add four to each of the numbers, find the sum of each column and then divide each column by 10. The numbers shown in row 4 of table 3 each represent a planet successively farther from the sun. The first is, of course, Mercury, the second Venus, the third Earth, and the fourth Mars. The only other planets known to exist at that time were Jupiter and Saturn. At first Bode's "rule" met with little excitement. Then in the year 1781 Uranus was discovered. Bode merely extended his calculations which at that time had Saturn in the position farthest from the sun. Bode's calculation and the actual distance of Uranus from the sun closely agreed. Because of this a group of European astronomers began a vigorous search for the yet undiscovered planet between the orbits of Mars and Jupiter, which was predicted by Bode's "rule." In the year 1801 an object was discovered in this area.

21. Do you know what this object was?

The last two currently known planets in our solar system are Neptune and Pluto. Bode's "rule" can be applied to these two planets if you assign a distance of 30 astronomical units to Neptune and use an extention of Bode's calculations from Uranus to find the distance of Pluto from the sun. This lack of orderly progression of Bode's calculations for Neptune and Pluto can be explained by the fact that Pluto's orbit carries it between Neptune and Uranus at its closest approach to the sun. You can check some reference books to find reasons for Pluto's irregularities. It should be pointed out here that Neptune was discovered mathematically by its gravitational influence on the orbit of Uranus, and Pluto was discovered mathematically by its gravitational influence on the orbits of both Uranus and Neptune. This is just one of the many contributions mathematics has made in the space sciences.

……

Problems:

(Example) If an object is 0.4 astronomical units (AU) from the sun, what is its distance in miles?

$$0.4\text{AU} \times \frac{93{,}000{,}000 \text{ mi.}}{1\text{AU}} = 37{,}200{,}000 \text{ miles.}$$

22. Using Bode's "rule" (table 3), calculate the distance of the planets from the sun in (a) miles, and (b) kilometers. You may want to construct a chart to show the distances of the planets from the sun in astronomical units, miles, and kilometers.

    It might interest you to know how precise Bode's estimate of the planetary distances was. This can be calculated by using the following relationship; $\frac{\text{correct value} - \text{Bode's value}}{\text{correct value}} \times 100$ = percent of error.

(Example using the distance of Mars from the sun)

$$\frac{1.52 - 1.6}{1.52} \times 100 = 5.3 \text{ percent of error}$$

23. Calculate the percent of error of Bode's planetary estimates for each planet using the figures in table 3. What do you think of the accuracy of Bode's planetary estimates? Keep in mind that his work was done in the 1700's.

24. The closest visible star to the Earth, other than the sun, is Alpha Centauri. If Alpha Centauri is 25,240,000,000,000 miles away, how many astronomical units does this distance equal?

25. Using scientific notation what is the distance to Alpha Centauri in miles?

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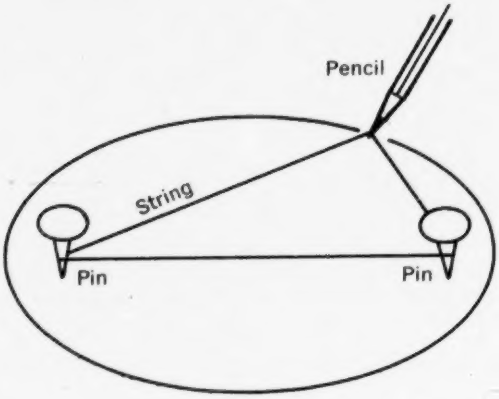


Figure 9.

As was previously mentioned, the planets and their satellites do not have circular orbits, but elliptical orbits. You can draw an ellipse. All you do is to take two pins and stick them into a piece of paper. Then taking a piece of string and a pencil, draw the ellipse as is shown below in figure 9. As you move the pins farther apart and still use the same length of string, you will see that the new ellipse is elongated. If, on the other hand, you move the pins closer together, you will see that the ellipse becomes more nearly circular.

Anything with an elliptical orbit will have its *primary* at one of the two pin holes. These pin holes are called the *focii* (fō-sī, plural for focus) of the ellipse. As you can see from figure 9, and from your own drawings, the distance of the pencil point from any one of the pins changes constantly as the pencil is moved to trace the ellipse. A planet or satellite with an elliptical orbit will also be at different distances from its primary as it moves along its elliptical path. Figure 10 shows the names for the two special points of elliptical orbits which bring the object closest to and take it farthest away from its primary.

What do the prefixes and suffixes mean in figure 10?

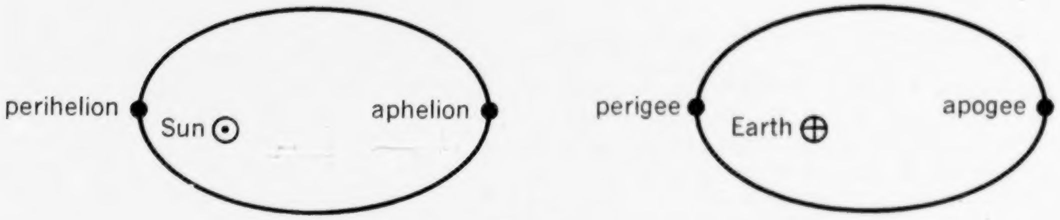


Figure 10.

Problems:

26. Calculate the average distance that the satellites in table 4 were from the Earth when they were launched into their orbits in (a) miles, and (b) kilometers.

27. If the moon's perigee distance is 221,463 miles and its apogee distance is 252,710 miles, what is the moon's average distance from the Earth in (a) kilometers, and (b) astronomical units?

28. If a particular comet has a perihelion distance of 0.05 of an astronomical unit and an aphelion distance of 87.41 astronomical units, what will be the average distance of this comet from our sun?

29. If a moon probe were to place a satellite in an orbit around the moon with a "perilunar" distance of 9,000 kilometers and an "apolunar" distance of 14,000 kilometers, what would be the average distance of this satellite from the moon?

TABLE 4.—Distances of satellites

Satellite	perigee distance	apogee distance
Explorer VII	344 miles	673 miles
Echo I	945 miles	1049 miles
Orbiting solar observatory (OSO)	343.4 miles	369 miles
Explorer XIV	174.2 miles	61,190 miles
Relay I	1316.5 kilometers	7423.5 kilometers
Syncom II	35,790.5 kilometers	35,805.9 kilometers
TIROS VIII	702 kilometers	753 kilometers

Eccentricity

As was previously mentioned in the experiment on drawing an ellipse, the farther apart the two pins are moved the more elliptical or elongated the ellipse will become. *Eccentricity* describes the shape of the ellipse, which is indicated by a number from zero (a circle) to nearly one. If the eccentricity becomes one, the curve is no longer an ellipse but a parabola. Eccentricity is quite important to scientists when launching a satellite. A weather satellite, such as TIROS, must remain at a constant distance from the Earth to give us the best results. Hence, low eccentricity is desirable in such an orbit. On the other hand, a space probe such as Explorer XIV requires a satellite to take measurements over a wide range of distances from the Earth. In this case an orbit of high eccentricity would be desirable. The eccentricity (e) of an orbiting object can easily be calculated by using the relationship $e = \frac{c}{a}$.

Focal Length

In astronomy there are many areas where astronomers are concerned with distance calculation. One of these areas is the calculation of the focal length of mirrors in reflecting telescopes, which are used to study objects in space. The focal length is the distance from the mirror to a point upon which light rays are focused after being reflected by the mirrors. Mirrors are used in the largest optical telescopes, such as the 200-inch reflecting telescope at the Mount Palomar Observatory in California.

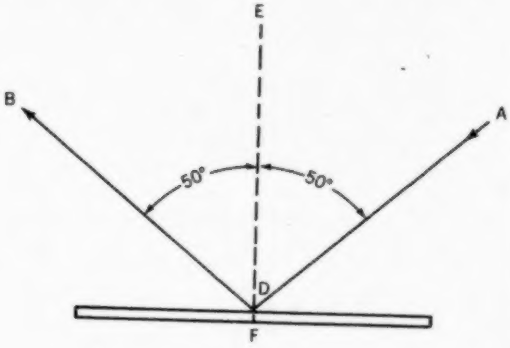


Figure 3.

Any line which is perpendicular to another line is called a *normal.* In figure 3, line EF is a normal to the surface of the mirror. If the incident light ray (line AD) is 50° from the normal, then the reflected light ray (line DB) will also be 50° from the other side of the normal. This, simply, is the law of reflection: The angle of the incident light ray is equal to the angle of the reflected light ray.

……

Problems:

8. If the incident light ray is 75° from the normal, what will be the angle of the reflected light ray?
9. If the reflected light ray is 19° from the normal, what was the angle of the incident light ray?
10. (a) If the incident light ray is parallel to the normal, where will that light ray be reflected?

    (b) What will be the angle between the reflected ray and the normal?

……

Flat mirrors are not used as the principal mirrors in reflecting telescopes, because a flat mirror will not focus incident light rays to a point. A simple kind of

C = center of Curvature

CD = CB = radius of Curvature (R)

CB = the normal to the incident light ray AB and the reflected light ray BE

ABC = angle of incidence

CBE = angle of reflection

i = r

f = focal point of mirror

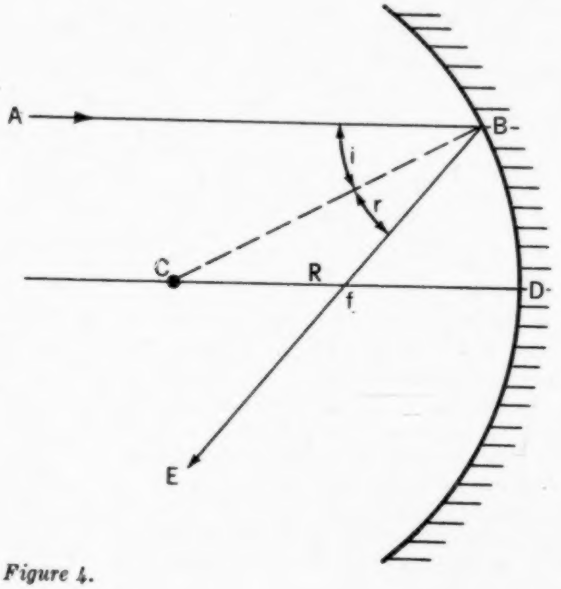


Figure 4.

curved mirror is a spherical mirror where the reflecting surface is part of a spherical object (a ball). Spherical mirrors (see following discussion of parabolic mirrors) used in astronomy are concave spherical mirrors; that is, the reflecting surface would be the inside of a ball-shaped object. To find the focal point of a concave spherical mirror you need know only the radius of curvature of the mirror, which is the same as the radius of the imaginary sphere of which the mirror is a part. Figure 4 shows a cross-section of a concave spherical mirror. The focal point or focal length (f) of a concave spherical mirror is $\frac{1}{2}$ the radius of curvature (R). This can be expressed symbolically as $f = \frac{R}{2}$

……

Problems:

11. Find the focal length of the following concave spherical mirrors using the given radius of curvatures; (a) 18 inches, (b) 3 feet, (c) 31 feet, 3 inches, (d) 71 feet, (e) 99 feet, 4 inches, (f) 75 centimeters, (g) 1 meter, (h) 17 meters, (i) 41 meters, (j) 38.4 meters.
12. (a) Which of the mirrors in problem 11 is the most curved (having the smallet radius of curvature)? (b) Which of the mirrors in problem 11 is the least curved (having the longest radius of curvature)?
13. The Schmidt telescope of the Palomar Observatory has a concave spherical mirror with a radius of curvature equal to 20 feet. Find the focal length of this mirror in (a) feet, and (b) meters.

……

Using spherical mirrors in reflecting telescopes, however, presents a problem. Spherical mirrors focus with sufficient accuracy only those light rays which are reflected from the near-center of the mirror. If a light ray is reflected from the near-edge of the mirror, it is focused behind the point where reflected rays closer to the center of the mirror are focused. This effect, called spherical aberration, is remedied in the Schmidt telescope by using a corrective lens. Spherical aberration, shown in figure 5, destroys the sharpness of the image at the focal point of the mirror.

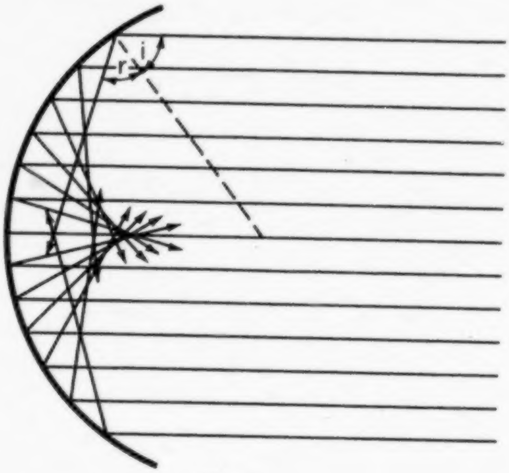
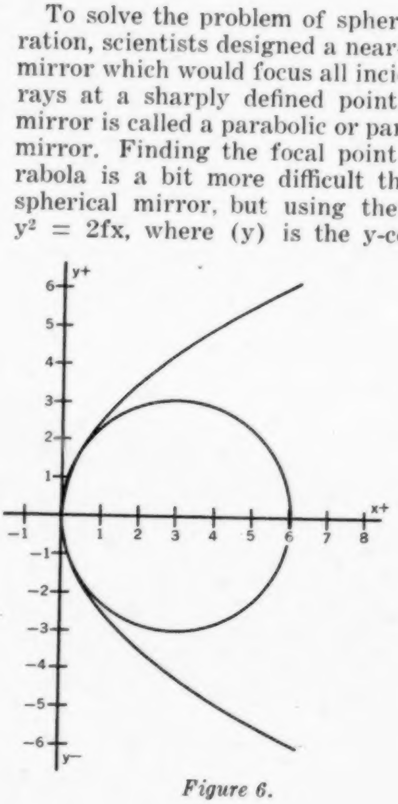


Figure 5.

To solve the problem of spherical aberration, scientists designed a near-spherical mirror which would focus all incident light rays at a sharply defined point. Such a mirror is called a parabolic or paraboloidal mirror. Finding the focal point of a parabola is a bit more difficult than for a spherical mirror, but using the formula $y^2 = 2fx$, where (y) is the y-coordinate



f = 3

y	x
0	0
±2	⅔
±3	1½
±4	2⅔
±5	4-1/6
±6	6

Figure 6.

See figure 11 for the meaning of (a) and (c). AF_1 = perigee distance. BF_1 = apogee distance.

$$a = AD \text{ or } \frac{\text{perigee + apogee distance}}{2}$$

$$c = AD - \text{perigee distance} = \text{line } DF_1$$

$$c = AD - AF_1 = DF_1$$

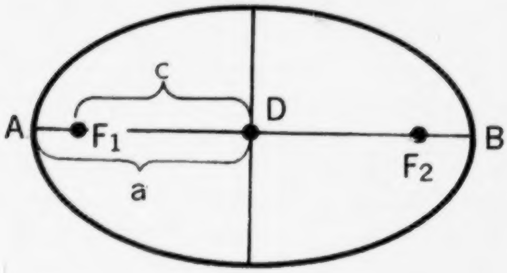


Figure 11.

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Problems:

30. One of the first successful launches by the Goddard Space Flight Center was Explorer VI in August, 1959. One of the tasks of Explorer VI was to measure various levels of radiation in the Van Allen belts around the Earth. (Do you think that this satellite was launched into an orbit of high eccentricity?)

31. Calculate to three decimal places the eccentricity of the orbit of Explorer VI if its perigee distance, were 157 miles and its apogee distance were 26,357 miles.

32. Pioneer V was designed and launched into an orbit around our sun to investigate interplanetary space. If the perihelion distance of Pioneer V were 74.9 million miles and its aphelion distance were 92.3 million miles, calculate the eccentricity of its orbit to three decimal places.

33. TIROS II was launched in November, 1960. One of its tasks was to televise and transmit information on cloud cover over the Earth. Do you think the orbit of TIROS II was planned to have high or low eccentricity?

34. Calculate to three decimal places the eccentricity of the orbit of TIROS II if its perigee and apogee distances were 407 and 431 miles respectively.

35. The Orbiting Solar Observatory, OSO I, was launched in March, 1962, into an orbit with perigee and apogee distances of 343.5 and 369.8 miles respectively. Calculate the eccentricity of its orbit to three decimal places.

36. On July 26, 1963, Syncom II was launched. This satellite was to have a 24-hour orbit which, if successful, would appear to remain stationary over a certain point on the Earth. To have such an orbit, would Syncom II have high or low eccentricity?

37. If the orbit of Syncom II has perigee and apogee distances of 22,230.1 and 22,239.7 miles respectively, calculate

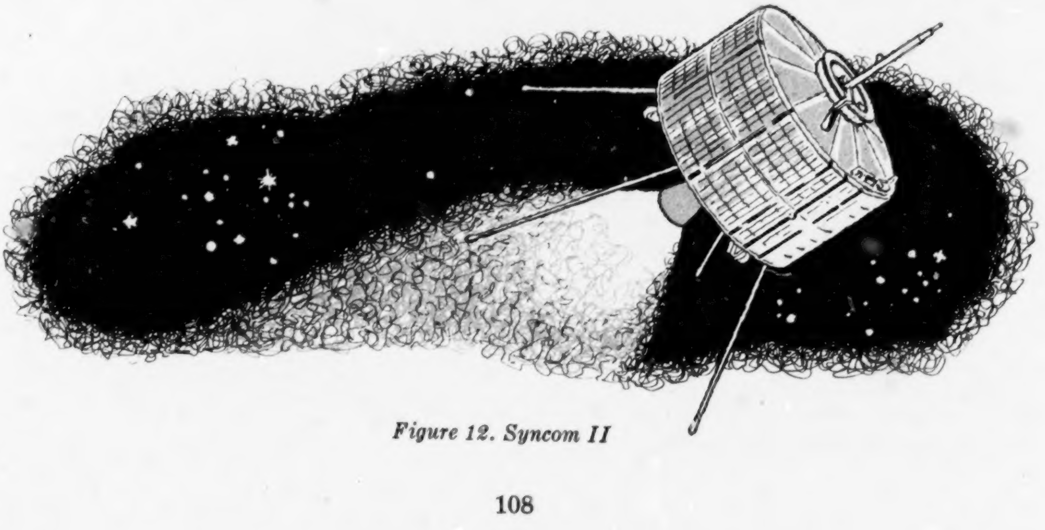

Figure 12. Syncom II

to seven decimal places the eccentricity of its orbit and round off to six decimal places.

38. For those of you for whom mathematics is a challenge, complete table 5. Refer to figure 11 when needed.

TABLE 5.—Distances in astronomical units

Planet	Perihelion distance	Aphelion distance	Average distance*	(c) Figure 12	Eccentricity*
Mercury	0.3076	0.4666			
Venus	0.7182	0.7284			
Earth			1.0000	0.0170	
Mars			1.5237	0.1417	
Ceres (Asteroids and Planetoids)			2.7673		0.077
Jupiter			5.2028	0.5342	0.048
Saturn				0.9016	0.056
Uranus					0.047
Neptune	29.7812		30.0577		
Pluto		49.3576	39.5177		

From: Robert H. Baker, Astronomy (New York: D. Van Nostrand Company, Inc., 1959).

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VELOCITY

So far during the entire discussion, we were concerned with distance measurements which were unrelated to time. Now we are going to introduce time measurements with distance to get a new quantity. This new quantity describes how much distance is traversed in a certain amount of time. For example, if you can walk four miles in one hour in a given direction, you are walking with a *velocity* of four miles per hour. Velocity also implies direction indicated usually with a vector. Velocity (v) is related to the distance (d) and the time (t) in the following way; $v = \frac{d}{t}$.

……

Problems:

39. If a particular satellite traveled 30,000 miles in 6 seconds, what would the velocity of that satellite be in miles per second?

40. If Vanguard III were traveling with a velocity of 18,522 miles per hour at perigee after launching, what is the velocity in (a) miles per minute, (b) miles per second, and (c) kilometers per second?

41. Vanguard III had a perigee velocity of 29,820 kilometers per hour and an apogee velocity of 20,349 kilometers per hour. (a) What was the average orbital velocity of Vanguard III? (b) What was the same average orbital velocity in kilometers per second?

42. If the light arriving here this moment left the sun $8\frac{1}{3}$ minutes ago, how fast does light travel in (a) miles per second, and (b) kilometers per second? (Assume the Earth is 93,000,000 miles from the sun.)

Probably without realizing it, you have just calculated the approximate velocity of light; the correct value being 186,272 miles per second. Knowing the velocity of light enables you to calculate the distance light travels in a given amount of time. By changing the original velocity equation $v = \frac{d}{t}$ to $d = vt$ you can easily solve for the distance.

43. Calculate the distance light travels in one year (365.25 days) in (a) miles,

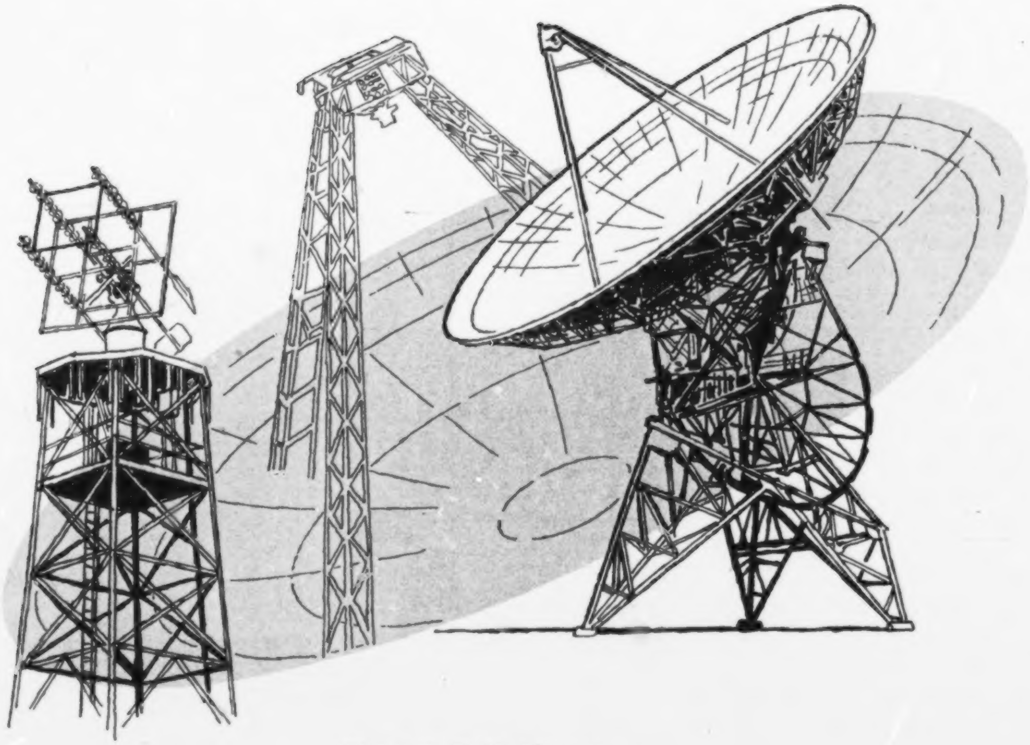

Figure 13. Radio telescope

(b) kilometers, and (c) astronomical units.

The distance you have just calculated in problem 43 is the distance light travels in one *light year.* The light year, as a unit of measurement, is used to describe the distances to the nearby stars, not to mention the more distant stars and galaxies.

44. What is the diameter of the Milky Way (the galaxy in which we live) in light years if an object traveling with a velocity of 0.484 the velocity of light must travel 206,612 years to cross our galaxy?
45. In the near future, man may venture a trip to the closest visible star, Alpha Centauri. If the space vehicle could travel at 0.43 the velocity of light, and the trip took 10 years, how far away is Alpha Centauri?
46. If a satellite were launched into a near circular orbit 35,400 kilometers from the Earth and had a velocity of 10,950 kilometers per hour, what distance in kilometers would be covered in one orbit if the period of revolution was 23.3 hours?

The time required for a signal to travel from a satellite to the Earth can be used to calculate how far away that satellite is from the Earth.

47. If it takes 4.00 seconds for the information sent by a space probe satellite to reach the Earth, how far from the Earth is that satellite?
48. Radio astronomy is a relatively new method of studying celestial objects. If a radio signal were sent toward a distant object in the sky and were reflected back to Earth by that object, how far from Earth would that object be if the time between the sending and receiving of the radio signal were 31 years? (Radio waves travel at the same velocity as does light.)

The time required for something to travel a given distance at a certain velocity can be calculated by using another

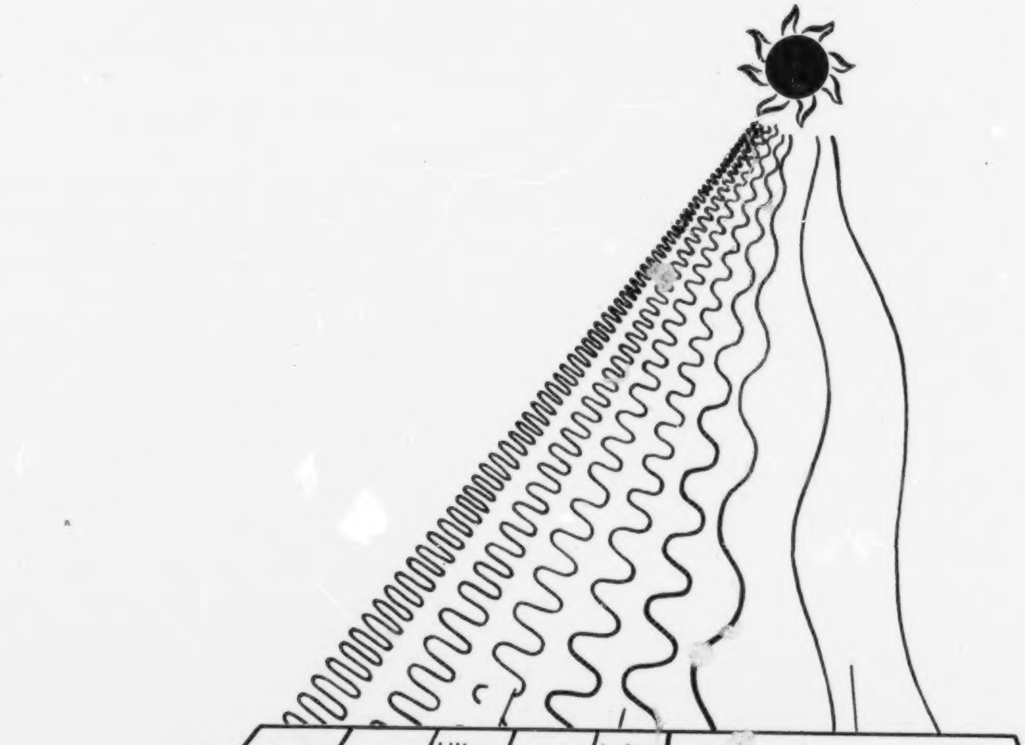
Gamma Rays
X-Rays
Ultra-violet
Visible
Infra-red
Radar
Radio
ATMOSPHERE
O3
H_2O
CO_2
EARTH
WINDOW
WINDOW
IONOSPHERE

Figure 14

From: Robert H. Baker, Astronomy (New York: D. Van Nostrand Company, Inc., 1959).

variation of the velocity formula $v = \frac{d}{t}$.

By solving for (t) you would get $t = \frac{d}{v}$.

49. If light travels 93 million miles from the sun to the Earth (1 astronomical unit) and has a velocity of about 186,000 miles per second, how long would it take for the light to get from the sun to the Earth?
50. How long does it take light to travel from the sun to the planet Saturn? (Check table 3 for Saturn's actual distance from the sun in astronomical units.)
51. If you were on the moon, how long would it take a radio signal sent by you to reach the Earth? (Check the answer sheet, problem 27 for the moon's average distance from the Earth.)

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Wave Length

Visible light is termed as electromagnetic radiation. The visible spectrum can be broken down by a prism or other refractive devices into its various colors because each color has a different wave length (table 6). An easy way to remember the order of the colors from the long to the short wave length is to take the first letter of each color and make the name "ROY G. BIV."

TABLE 6.—Colors in a spectrum

Red	Orange	Yellow	Green	Blue	Indigo	Violet

Visible light, however, is just a very small part of the total electromagnetic radiation spectrum, which is shown below in figure 15.

All the various forms of electromagnetic radiation travel at the same velocity but differ in wave length as is shown below in figure 15.

……

Problems:

52. If a solar disturbance occurred this moment on our sun, how long would it take gamma radiation to reach the Earth if the Earth is exactly 1 astronomical unit away from the sun?
53. The Crab Nebula, a famous radio source, was a star which became a nova when it exploded some 4,410 years ago. The Chinese, in the year A.D. 1054, recorded seeing this star greatly increase in brightness. (a) During what possible Earth year did the star that produced the Crab Nebula explode? (b) How far away in light years is the Crab Nebula?
54. Suppose a star within our galaxy (the Milky Way) exploded and became a nova on December 31, A.D. 1964. How far away would this nova be if the radio noise (radiowave radiation) from the explosion did not reach the Earth until December 31, A.D. 66,964?

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Wave Length and Frequency

Another aspect of velocity is the motion of stars and galaxies, including our own Milky Way. To understand these velocities you must first know something about wave length and frequency. The wave length of any particular radiation is determined by starting at a particular point on a wave and moving along it until encountering another point on the wave which is identical to the point from which you started.

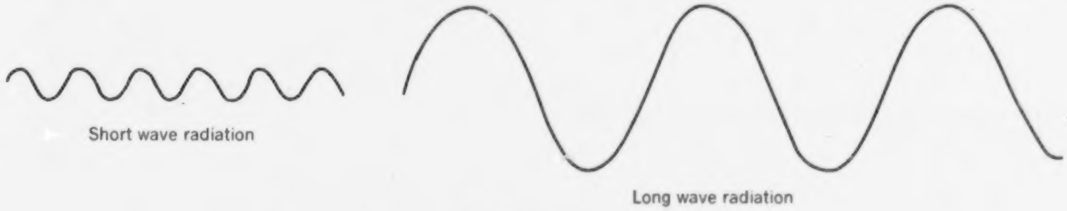

Figure 15.

This is shown below on figure 16. Any wave length is the distance between the points A and A^1, or between the points B and B^1, C and C^1, or D and D^1. This wave length (λ—lambda) is different for all the types of radiation shown on Table 6 as well as on Figure 14. These wave lengths vary in length from 0.000000000001 centimeter in gamma radiation to 1 million centimeters in radiowave radiation.

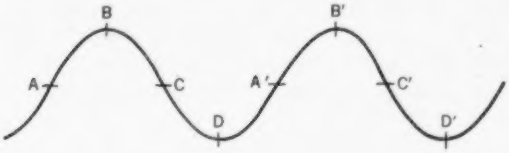

Figure 16.

The frequency of a wave is determined by the number of wave lengths passing a given point in a certain amount of time. For example, if 1,350 wave lengths pass a point in 1 second, the frequency of this radiation would be 1,350 wave lengths per second (commonly termed as cycles per second). Using wave length and frequency we can again find velocity. $v = f\lambda$ where (λ) is the wave length and (f) is the frequency. This formula can also be solved for $\lambda = \frac{v}{f}$ or $f = \frac{v}{\lambda}$.

Problems:

55. Since all types of radiation have the same velocity, what can you say about the frequency of gamma radiation as compared with the frequency of radiowave radiation?

56. The human eye can see electromagnetic radiation wave lengths from about 0.00004 to 0.00007 centimeters in length. Knowing the velocity of light in centimeters per second (299,460,000,000 cm/sec) calculate the range in frequencies that the human eye can detect.

57. When the velocity of sound in air is 331.4 meters per second (velocity of sound varies at different altitudes and temperatures), what will the wave length of a sound wave be from a sound source emitting a frequency of 256 cycles per second?

58. A typical human ear can hear frequencies between 20 and 20,000 cycles per second. Again assuming the velocity of sound to be 331.4 meters per second, what is the range in wave length that a typical human ear can detect in (a) centimeters, (b) meters, and (c) feet?

59. If a satellite was transmitting at a wave length of 0.00270 meters, to what frequency would the receiving sets on the Earth have to be tuned to receive the signals? (Check problem 42(b) on the answer sheet for the metric value for the speed of light.)

Doppler Effect

Wave length and frequency can also be used to determine the velocity of a sound or light source which is in motion either toward or away from the observer. When a sound or light source is in motion relative to the observer, there is a shift in the wave length of the sound or light. This is known as the Doppler effect. As far as sound is concerned, you may try the following experiment. If you were to stand along a highway while a friend blows the automobile horn while driving past you, a change in the pitch of the sound would be quite easily noticed. The automobile horn sends out the same number of wave lengths per second (frequency) while it is at rest or while it is moving. The velocity of the sound coming from the horn is also constant for each particular instance.

If the sound source is moving toward you, as is shown in figure 17, the wave lengths are crowded together and thereby shortened. This would cause a higher pitch in the sound heard by the observer. On the other hand, if the sound source is moving away from the observer the wave lengths are stretched out and thereby lengthened. This would cause a lowering of the pitch heard by the observer (also shown in figure 17). The above situation is identical with that of a passing train.

This same lengthening and shortening of wave lengths is present when an elec-

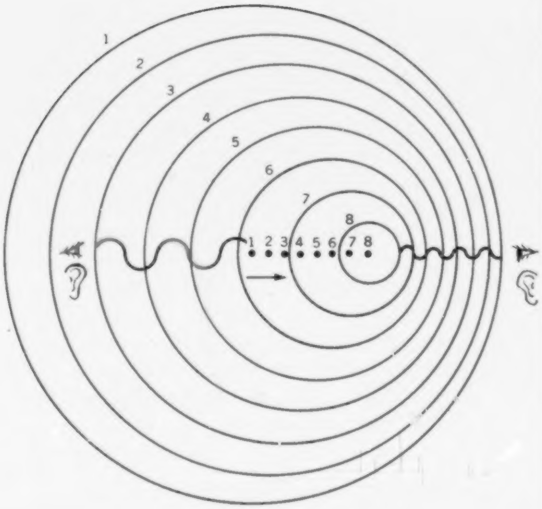

Figure 17. The Doppler effect

From: George Gamow, Matter, Earth and Sky (Englewood Cliffs: Prentice-Hall, Inc., 1964).

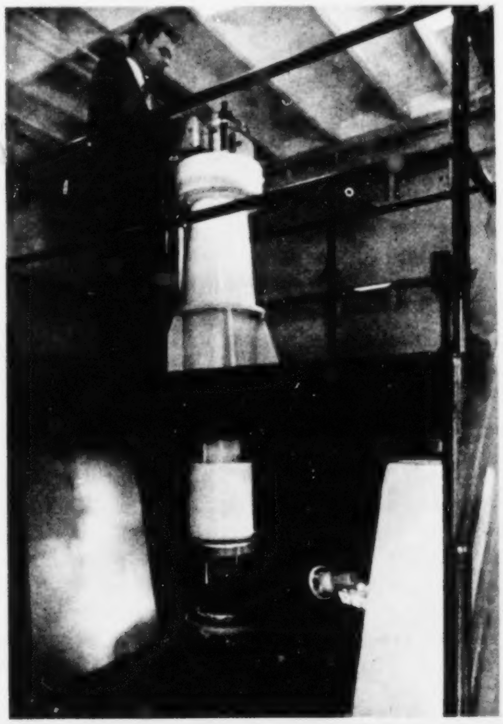

Figure 18. Spectrogram

From: Robert H. Baker, Astronomy (New York: D. Van Nostrand Company, Inc., 1959). Permission to use this photograph was obtained from Mount Wilson and Palomar Observatories, Carnegie Institute of Washington, Pasadena, California.

tromagnetic radiation source (a star) and the Earth are moving toward or away from each other. Since we speak of electromagnetic radiation as an entire spectrum (figure 14) the instrument which records these wave lengths is called a spectrometer. Spectrometers record information on a photograph called a spectrogram. Each wave length which is present is represented by a well defined bright or dark line, depending on what is being photographed. Such a spectrogram is shown on figure 18. These spectral lines can be measured to indicate what elements are present in the electromagnetic radiation source.

Figure 19 shows a drawing of a spectrogram of moving electromagnetic radiation sources compared with the spectrogram of a stationary source of electromagnetic radiation as can be obtained in a laboratory.

The Doppler effect can be expressed mathematically as $\frac{\text{change in wave length}}{\text{normal wave length}} = \frac{\text{velocity of source}}{\text{velocity of light}}$. This expression may be solved for any one of the four quantities contained in it.

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Problems:

60. The sun (and the solar system) is speeding toward the constellation Cygnus with a velocity of 216 kilometers per second. If a radio astronomer were to transmit a radio signal toward the constellation Cygnus with a wave length of 0.003500000 meter, what change in wave length would be observed by a possible intelligent race receiving the signal on a planet revolving around a star in this constellation?

To find the wave length of the radio signal received on such a planet as mentioned in problem 60, subtract the change in wave length from the signal transmitted from Earth.

61. Calculate the wave length radio signal that would be received by someone on the possible planet mentioned in problem 60.

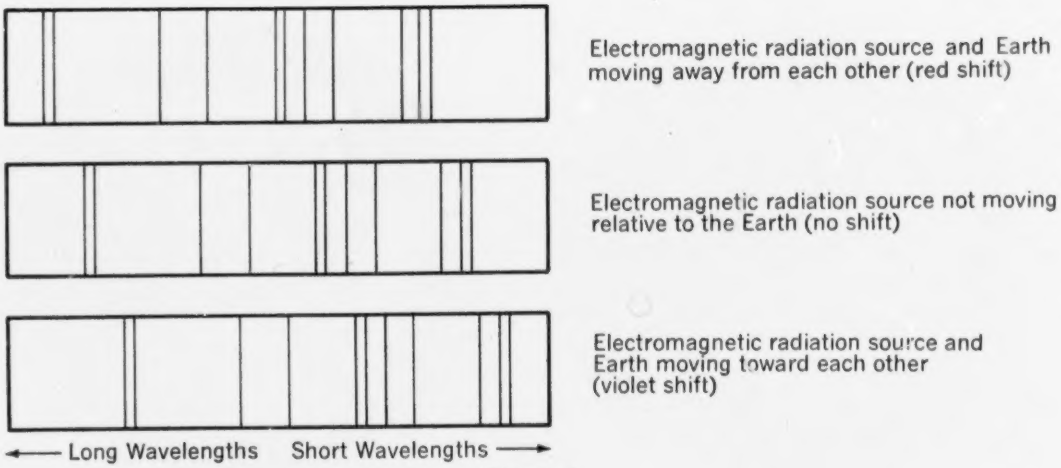
Electromagnetic radiation source and Earth moving away from each other (red shift)
Electromagnetic radiation source not moving relative to the Earth (no shift)
Electromagnetic radiation source and Earth moving toward each other (violet shift)
← Long Wavelengths
Short Wavelengths →

Figure 19.

62. If a satellite were launched into an orbit of high eccentricity around our sun, what would be its velocity at perihelion if the signal it transmitted had a wave length of 7.200 millimeters and the wave length signal received on Earth was 7.197 millimeters? (Note: change in wave length = wave length transmitted — wave length received.)

The larger reflecting telescopes study the motions of galaxies so distant that the light we observe now left those galaxies before the Earth was formed (Earth is about five billion years old). Generally, the more distant a galaxy, the faster it is moving away from us.

63. If the spectral lines of a galaxy were lengthened by $\frac{1}{4}$ of its normal wave length, how fast would that galaxy be speeding away from us?

An angstrom unit is a very small unit of linear measurement which is 0.00000001 centimeter long.

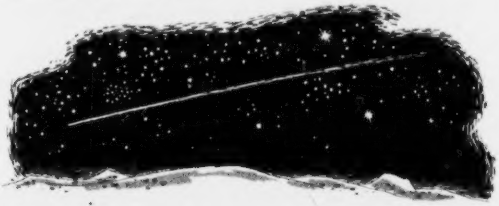

Figure 20. Meteortrails

64. How many angstrom units are there in (a) 1 centimeter, and (b) 1 meter?

65. If an astronomer were recording meteor trails on a spectrogram and noticed that a spectral line for calcium which is normally 6,182 angstrom units long were shortened 1.429 angstrom units, how fast would that meteor be moving through our atmosphere in (a) miles per second, and (b) kilometer per second?

66. Suppose a scientist were to point a spectrometer toward the burning gases roaring from a Saturn, Thor, or Atlas booster engine. If the resulting spectrogram were to show the 6,640.900 angstrom units spectral line for oxygen to be displaced 0.054 angstrom unit, what would be the velocity of the gases being expelled from the above booster engines in (a) kilometers per second, (b) miles per second, (c) kilometers per hour, and (d) miles per hour?

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ACCELERATION

You should now have a fair idea of what is meant by the concept velocity. In short it is a constant rate of motion in a given direction. By this is meant that an automobile traveling with a velocity of 50 miles per hour will experience no other quantity of linear motion as long as it continues moving at 50 miles per hour in

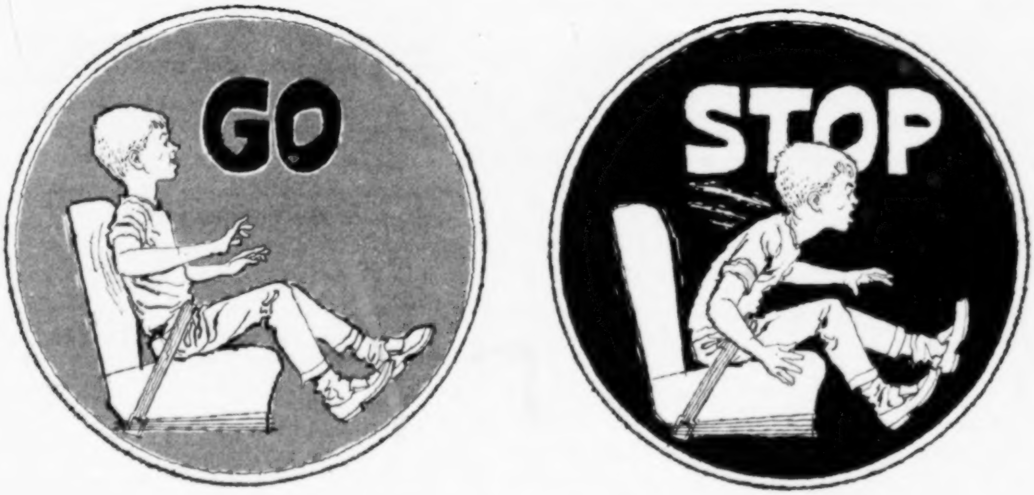

Figure 21. Acceleration effect

the same direction. The moment the automobile or any other moving object increases or decreases its velocity, it experiences acceleration or deceleration respectively. For example, an airplane accelerates during take-off, cruises at a certain velocity in a given direction, and then decelerates during landing. Deceleration is sometimes termed as negative acceleration. A simple kind of acceleration is that of a freely falling object. Figure 22 shows a ball being dropped from a building 256 feet high. It takes 4.0 seconds for the ball to reach the ground. If you wanted to find the acceleration due to gravity of a freely falling object, the formula $d = \frac{1}{2}at^2$ could be used. The letter d again is the distance, a the acceleration, and t the time.

Example Using Figure 22:

(1) solving for a, the above formula becomes $a = \frac{2d}{t^2}$.

(2) $a = \frac{2 \times 256}{(4)^2} = \frac{512}{16} = 32$ feet per second^2 or 32 feet per second per second. The units for acceleration mean that the object is accelerating 32 feet per second every second that it falls.

Problems:

67. Knowing the acceleration due to gravity (above example), calculate the distance the object in figure 22 falls by the end of each second.
68. How long would it take an object to fall 1,024 feet?
69. If you were to launch a model rocket to a height of 2,000 feet in three seconds, calculate the approximate acceleration of the rocket.
70. How long would it take for a rocket with zero velocity at 2,000 feet to fall back to the Earth?
71. If the first booster on a launch vehicle burns for 8 seconds, is separated from the launch vehicle, and then starts descending from an altitude of 1 kilometer, how long would it take for this spent booster to splash into the ocean? (Note: you will need to change acceleration due to gravity into the metric system.)

To further develop the situation, suppose a ball were to be thrown vertically to a height of 100 feet. On its way up the ball would decelerate until it reached its maximum height, where it would momentarily stop before beginning its fall to the ground (velocity at this point is equal to zero). Deceleration due to gravity is such that when an object coasts upward after being propelled is — 32 feet per second^2. During its fall to the ground it would experience the same acceleration as did the ball dropped from the building in figure 22.

It might interest you to know the velocity of an object which has been propelled upward. To find this you can use the following relationship: $a = \frac{v_f - v_i}{t}$, where (a) is the acceleration due to gravity, (v_f) is the final velocity, (v_i) is the initial velocity, and (t) is the time. This formula is unique in that it clearly shows when the acceleration is (+) or (—). On its journey upward its final velocity is zero at the maximum height where the ($-v_i$) shows the acceleration to be (—). On its fall downward the initial velocity is zero at the maximum height so the (v_f) shows the acceleration to be (+).

Example Using Figure 23:

If you shot an arrow vertically to a height of 196 feet, (a) what is the time required for the upward flight, (b) what is the time interval between the time of shooting the arrow and the arrow striking the ground, (c) what is the velocity of the arrow when it leaves the bow, and (d) what is the velocity of the arrow when it strikes the ground?

(a) $d = \frac{1}{2} at^2$, $t^2 = \frac{2d}{a} = \frac{2 \times 196}{32} = \frac{392}{32} = 12.25$

$t = 3.5$ seconds.

(b) time up = time down. $t = 3.5 \times 2 = 7$ seconds.

(c) $a = \frac{v_f - v_i}{t}$, $v_f - v_i = at$

$0 - v_i = -32$ feet per sec.$^2 \times 3.5 = 112.0$ feet per sec.

(d) $v_f - v_i = at$, $v_f - 0 = 32$ feet per sec.$^2 \times 3.5$ sec. $v_f = 112.0$ feet per second.

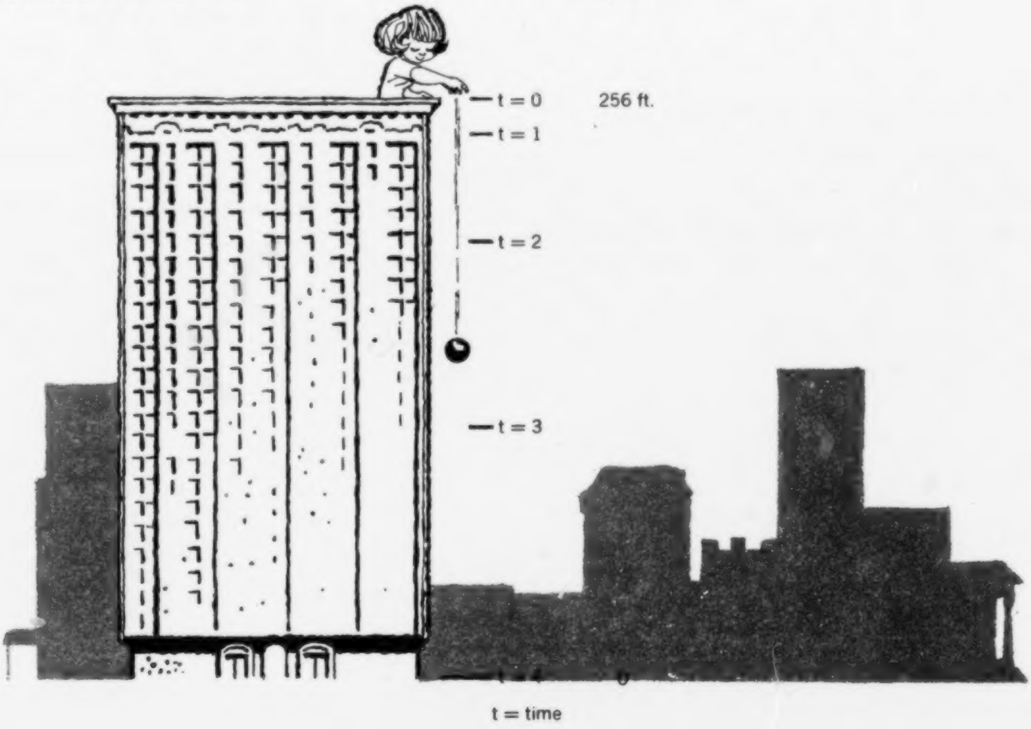

Figure 22.

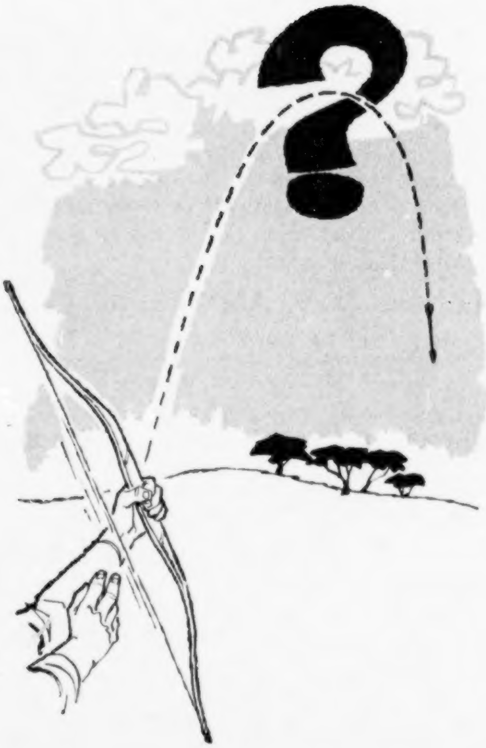

Figure 23. Flight of an arrow

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Problems:

72. Find the impact velocity of the rocket mentioned in problem 69 in feet per second.
73. Find the impact velocity of the booster mentioned in problem 71 in meters per second.
74. Suppose you were on the moon where the acceleration due to gravity is 1.67 meters per second^2 and you shot an arrow with an initial vertical velocity of 33.6 meters per second, (a) what would be the time of the entire flight of the arrow, and (b) how high would the arrow soar in meters?
75. If an object is thrown vertically to a height of 78.4 meters in 4 seconds, calculate the acceleration due to gravity for the Earth in (a) centimeters per second^2, and (b) meters per second^2.
76. If an object were propelled vertically from the surface of our sun to a height of 2,195 meters and it landed 8 seconds later, calculate and compare the acceleration due to gravity on the sun with that of the moon and the Earth.

••

PROJECTION

The material presented in this chapter may have captured your interest, but what is yet to be learned stretches far beyond the imagination. Discovery and understanding depend on you, who can be and hopefully who will be the mathematicians and scientists of the future.

Some of you may think that the mathematical processes and problems in this booklet are simple, but be assured that the more proficient you become with numbers and number relationships, the more exciting will be the problems you will be able to solve.

ANSWERS

Chapters I through VI

and

SELECTED BIBLIOGRAPHY

Chapter I – FROM HERE, WHERE?

Table 2.–Our solar system

Name		Symbol	Mean Distance from Sun		Period of Revolution		Eccentricity of Orbit	Mean Diameter in Miles	Mass ⊕=1	Density $H_2O=1$	Period of Rotation	Stellar Magnitude at Greatest Brilliance	Escape Velocities
			Astron. Units	Million Miles	Sidereal	Synodic							
Inner	Mercury	☿	0.3871	35.96	days 87.969	days 115.88	0.206	2,900	0.05	6.1	88 days	—1.9	2.6 miles/sec
	Venus	♀	0.7233	67.20	days 224.701	583.92	0.007	7,600	0.81	5.06		—4.4	6.4 miles/sec
	Earth	⊕	1.0000	92.90	days 365.256		0.017	7,913	1.00	5.52	23^h56^m		7 miles/sec
	Mars	♂	1.5237	141.6	days 686.980	779.94	0.093	4,200	0.11	4.12	24^h37^m	—2.8	4 miles/sec
Outer	Jupiter	♃	5.2028	483.3	years 11.862	398.88	0.048	86,800	318.4	1.35	9^h50^m	—2.5	37 miles/sec
	Saturn	♄	9.5388	886.2	years 29.458	378.09	0.056	71,500	95.3	0.71	10^h02^m	—0.4	22 miles/sec
	Uranus	♅	19.1820	1783.0	years 84.013	369.66	0.047	29,400	14.5	1.56	10^h45^m	+5.7	13 miles/sec
	Neptune	♆	30.0577	2794.0	years 164.794	367.49	0.009	28,000	17.2	2.29	15^h48^m	+7.6	14 miles/sec
	Pluto	♇	39.5177	3670.0	years 248,430	366.74	0.249						
	Sun	☉						864,000	331,950	1.41	$24^d.65$	—26.8	387 miles/sec
	Moon	☾						2160	0.012	3.33	$27^d.32$	—12.6	1.5 miles/sec

Chapter II – GETTING INTO SPACE

EXERCISES:	A–1	23,791.9 lb.
	A–2	24,466.9 lb.
	A–3	3.7 lb.
	B–1	10,000 H.P.
	B–2	3,000 H.P.
	B–3	187,336 H.P.
	C–1	200 seconds
	C–2	100 lb. per second
	C–3	250 seconds
	D–1	3
	D–2	3600 lb.
	D–3	250 lb.

Chapter III – SPACE AND WEATHER

1. 10 to the second power
2. 10×10
3. 10 to the eighth power
4. $10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$
5. 100
6. 100,000,000
7. $8 \times 10 \times 10 \times 10 \times 10 \times 10$ or $8 \times 100{,}000$ or 800,000
8. 6000
9. 50,000
10. 1,500,000
11. 250,000,000
12. 5×10^3
13. 6.5×10^6
14. 3×10^4
15. 5.5×10^3
16. 1×10^{-5}
17. 6.5×10^{-4}
18. 0.0000000615
19. 0.0000000506
20. 0.00000345
21. 1×10^{-6}
22. 3×10^1
23. 7×10^2
24. 9×10^5
25. 4×10^1
26. 0.000001
27. 1000000
28. 100,000,000
29. 0.00000001
30. 0.00002541
31. 9×10^{18}
32. 70,000,000
33. 0.00000008
34. 0.000000000000003546
35. 1×10^6
36. 93×10^6
37. 1×10^{-7}
38. 74.4 to 99.2 miles
39. 62 miles
40. 186 miles
41. 29.92 inches, nearly 30 inches
42. 96.6 kilometers
43. 1^{-10} atm.
44. 7.6×10^{-8} mm. 2.992×10^{-8} in.
45. 3.9×10^{-11} in. – 3.9×10^{-12} in.
46. 1×10^{-12} or 10^{-12}
47. 1×10^{-14} or 10^{-14}
48. 62 miles
49. 93 miles
50. 124 miles
51. 186 miles
52. 372 miles
53. 7.60×10^{-4} mm. or 1×10^{-6} atm.
54. 2.992×10^{-3} inches
55. .000000000001 atm.
56. .0000000002 atm.
57. −73°C
58. −99.4°F
59. −23°C
60. −9.4°F
61. −73°C
62. −99.4°F
63. 1127°C
64. 2060.6°F
65. 1227°C
66. 2240.6°F
67. 460 statute miles
68. $5\frac{1}{4}$ inches
69. $2\frac{5}{8}$ inches
70. 20°
71. 26,310 cu. in.
72. 15.2 cu. ft. p. 15
73. 18.03 cu. ft. round off to 18.0 cu. ft.
74. TIROS V = 26,600 cu. in. TIROS VIII = 31,500 cu. in. (approximately)
75. 3,740,000 hp. approximately
76. 165,000 hp.
77. 66,000 hp.
78. 11 minutes 15 seconds
79. less
80. 437.0 statute miles
81. 690.0 statute miles

Chapter IV – SPACE NAVIGATION

1. Solution: $1'' = \frac{1}{12}$ ft., and 1 ft.

$$= \frac{1}{5280} \text{ mile, therefore,}$$
$$500{,}000'' = 500{,}000 \times 1''$$
$$= 500{,}000 \times \frac{1}{12} \text{ ft.}$$
$$= 41{,}667 \text{ ft.}$$
$$41{,}667 \text{ ft.} = 41{,}667 \times 1 \text{ ft.}$$
$$= 41{,}667 \times \frac{1}{5280} \text{ mi.}$$
$$7.8 \text{ miles.}$$

1″ = 8 miles (approximately), answer.

2. Since 1″ represents 8 miles approximately, 2½″ = 2½ × 1″ or 2½ × 8 mi. = 20 mi.
3. The measure between the two airports in inches is 3 11/16; the distance in miles is 29½.
4. The measure between the two airports in inches is $3\frac{3}{16}$. The distance between them is, therefore, 25½ miles.
5. TC from D to C is 60°.
6. TC from C to D is 240°.
7. TC from A to B is 78°.
8. Variation is 4°W.
9. MC = TC + Var. W
   MC = 78° + 4°
   MC = 82°
10. Correction or Variation is 3°E.
11. MC = TC − Var. E
    MC = 287° − 3°
    MC = 284°.
12. (a) MC = TC + Var. W
    TC = 301°
    Var. W = 3°
    MC = 301° m + 3°
    MC = 304°
    (b) The measure of the TC in inches is 6, therefore the distance is 48 miles.
13. The school is approximately 22° or 23° to the left of the TC at that point.
14. Vector AC = 2¼ inches or 4½ lb.
15. The general direction is south of east.
16. 48°, 150 mph approximately.
17. 48°, 142½ mph approximately.
18. z = 90° − alt. or 21° 30′
19. 26° 30′
20. 19° 08′
21. 41° 34′
22. 9° 55′
23. L = 39° 56′
24. L = 69° 40′
25. L = 31° 13′
26. (a) 5 hr. = 5 × 1 hr. = 5 × 15° = 75°
    (b) 135°, (c) 225°, (d) 50°, (e) 310° (f) 360°
27. A_c = hr.
28. Longitude = 119° 09′ W.
29. Latitude = 40° N.
    Longitude = 74° 10′
30. Philadelphia, Pennsylvania.
31. Latitude = 39° N. Longitude 77° 24′ W
    Washington, D.C
32. When its location was exactly south of the observer
33. The latitude of the observer, figure 22, is the declination of the zenith point.

    Angle d + angle z = 90°
    − Angle a + angle z = 90°
    by subtraction
    Angle d − angle a = 0°
    angle d = angle a
    This means that the declination of the zenith point is the same as the altitude of Polaris.
34. n_o = 296 cycles per second.
35. The speed is 67 mph, (rounded).
36. The car is within the legal limit. Its speed is 33 mph
37. θ, the central angle is 150°.
38. $\theta = 240°$.
39. $\theta = 180°$.
40. $\theta = 360°$.
41. The satellite will make one trip around the Earth in one day. Since the Earth rotates at the same rate, the satellite will appear to remain on the same meridian.

Chapter V – THE RIDDLE OF MATTER AND MOTION

a. The two coins or stones should always land together unless dropped from great distances where air drag would have a noticeable effect.

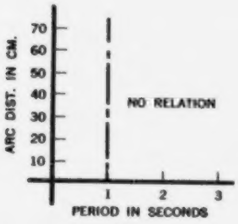
b. You should get the same results as before if the two objects are thrown to same height.

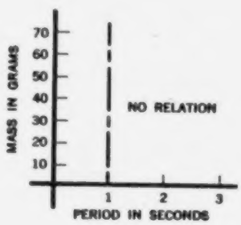
c. The arc distance for a sixteen degree swing is about 27.9 centimeters.

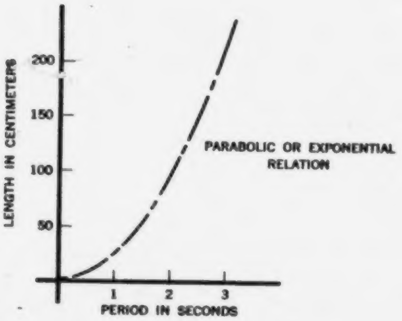
d. When sitting at rest, your heart should beat about three times during one period of a two meter pendulum.

e. Physicians probably compared the pulse rate of healthy persons to that of the patient before the pulsilogia. Doctors usually take a patient's pulse today by timing it with a watch having a "sweep" second hand.

f. Graphs







g. You can conclude that over the short distances involved, objects fall at the same rate regardless of their mass.

h. As the length of a pendulum is increased the period also increases. In order to double the period the length must be made 2^2 (or 4) times greater and in order to make the period three times greater, the length must be made 3^2 (or 9) times greater. It can be said then, that the length of a pendulum *varies* (or changes) with the square of the factor by which the period increases.

i. A "seconds pendulum" ($T = 2$ seconds) has a length of about .98 meters.

j. Tightly compacted (or *dense*) objects such as solid iron or lead balls are not effected by air resistance nearly as much as hollow or less dense objects.

k. The unfolded paper, of course, flutters in the restraining air while the more dense object falls quickly to the floor, but the tightly folded paper should reach the floor with the coin or stone for such short falls.

l. 176 feet per second.

m. One second and two seconds.

n. $\frac{\text{stick's shadow}}{\text{stick}}$ $\frac{\text{pole's shadow}}{\text{pole}}$

o. 3/72 or 1/24

p. The acceleration effect due to gravity (or g) will be reduced to 1/24th the free-fall acceleration by the inclined plane *directly;* but the energies required to set the jar in rotation, and to overcome the greater frictional drag, also to "dilute" gravity—resulting in a much greater overall reduction.

q.

Seconds of Elapsed Time	1	2	3	4
Approximate Distances for Straight Jar	4″	16″	36″	64″
Approximate Distances for Concave Bottle	5″	20″	45″	*

r. The distance rolled in two seconds should have been approximately four times the distance rolled in one second and the distance after three seconds should be nine times the *first* second's distance. The distance is increasing in direct proportion with the time squared just as the length of the pendulum was in direct proportion with the period squared. Algebraically stated then: $s \propto t^2$.

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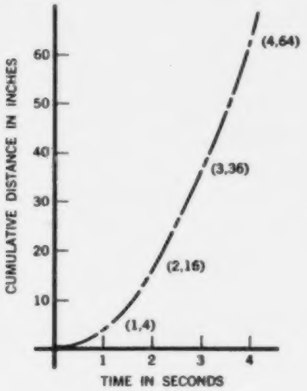
* The bottle with concave sides, apparently because of a lower friction factor, rolls faster than the straight sided jar and, as you may have discovered, has left the board within four seconds.

s. Graph.



t.

Time Interval in seconds	1	2	3	4
Avg. Velocity (in./sec.) of Jar	4	12	20	28 (projected)
Avg. Velocity (in./sec.) of Bottle	5	15	25	35

u. The average velocity of the jar increases about 8 in./sec. each second. The average velocity of the bottle increases about 10 in./sec. each second.

Numbered problems

1. About 4 seconds.
2. At least 320 meters (over 1000 ft).
3. About 80 seconds.
4. Yes, a sheer drop of over 882 meters (more than one half mile) is found at the site of Angel Falls in South America.
5. About 13 seconds.
6. About 80 feet.
7. About 144 feet.
8. About 584,040,000 miles.
9. About 3 and 2/11 feet in thickness.

Chapter VI – THE MEASURE OF SPACE

Earth-moon distance = 384,560 kilometers.
Time for satellite to get from Earth to Venus = 6,480,000 sec. = 1,800 hours = 75 days.
Velocity of satellite revolving around the Earth = 239 miles/minute (miles per minute).

TABLE I

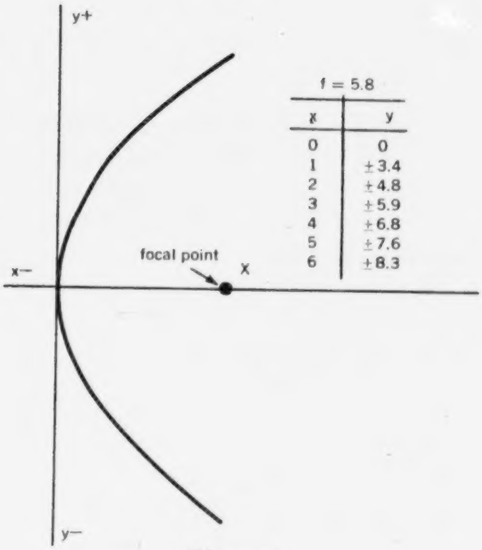
1 kilometer = 1,000,000 millimeters
1 meter = 100 centimeters
1 centimeter = 0.00001 kilometer
1 millimeter = 0.001 meter

TABLE II

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 mile = 1,610 meters
1 centimeter = 0.39 inch
1 meter = 39.36 inches
1 meter = 0.00062 mile

1. (a) 0.0001 to 0.1 centimeter, (b) 0.000039 to 0.039 inch
2. (a) 0.00178 centimeter, (b) 0.0178 millimeter
3. (a) 1,400 meters, (b) 4,583 feet, (c) 0.868 mile
4. (a) 690.2 to 750.1 kilometers, (b) 690,200 to 750,100 meters
5. 41.2 meters
6. (a) 6,370 to 50,960 kilometers (dwarf stars), (b) 1,391,040 kilometers (sun), (c) 625,968,000 kilometers (Betelgeuse)
7. 62,000 miles
8. Reflected light ray will be 75° from the normal
9. Incident light ray was 19° from the normal
10. (a) along the normal, (b) 0°
11. (a) 9 inches, (b) 1½ feet, (c) 15 feet 7½ inches, (d) 35½ feet, (e) 49⅔ feet, (f) 0.375 meter, 37.5 centimeters, 375 millimeters, (g) 0.5 meter, 50 centimeters, (h) 8.5 meters, 850 centimeters, (i) 20.5 meters, 2,050 centimeters, (j) 19.2 meters, 1,920 centimeters.
12. (a) most round, (i) flattest
13. (a) 10 feet, (b) 3 meters or 3.05 m.
14. f = 55.6 feet = 17 meters or 16.95 m.
15. f = 91.4 centimeters = 36 inches
16. f = 5.80 (graph—figure 24)
17. v = (a) 383 miles/sec. (b) 2,217,600 kilometers/hour (c) 1,378,800 miles/hour
18. See figure 25
19. See figure 26
20. 1 astronomical unit = 149,730,000 kilometers approximately
21. Ceres—one of the many asteroids or planetoids
22.

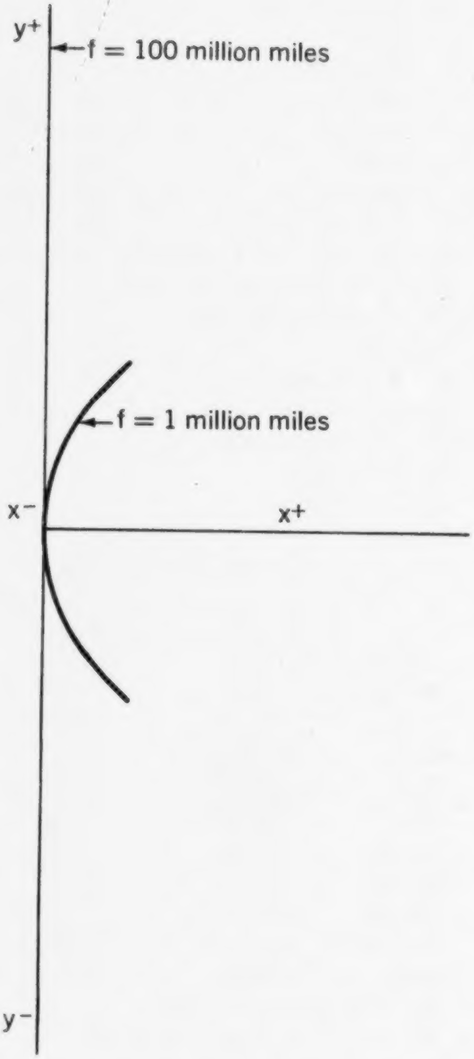
Mercury	(a)	37,200,000	miles	(b)	59,892,000	kilometers
Venus	(a)	65,100,000	miles	(b)	104,811,000	kilometers
Earth	(a)	93,000,000	miles	(b)	149,730,000	kilometers
Mars	(a)	148,800,000	miles	(b)	239,568,000	kilometers
Ceres	(a)	260,400,000	miles	(b)	419,244,000	kilometers
Jupiter	(a)	483,600,000	miles	(b)	778,596,000	kilometers
Saturn	(a)	930,000,000	miles	(b)	1,497,300,000	kilometers
Uranus	(a)	1,822,800,000	miles	(b)	2,934,708,000	kilometers
Neptune	(a)	2,790,000,000	miles	(b)	4,491,900,000	kilometers
Pluto	(a)	3,608,400,000	miles	(b)	5,809,524,000	kilometers



f = 5.8

x	y
0	0
1	±3.4
2	±4.8
3	±5.9
4	±6.8
5	±7.6
6	±8.3

Figure 24.



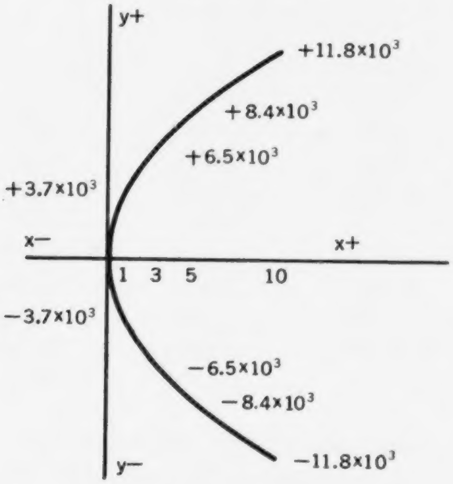


Figure 25.

Figure 26.

23.	Mercury	5.3	percent error (to nearest tenth)
	Venus	2.8	percent error
	Earth	0.0	percent error (because of definition of an astronomical unit)
	Mars	5.3	percent error
	Ceres	1.1	percent error
	Jupiter	0	percent error
	Saturn	4.8	percent error
	Uranus	2.2	percent error
	Neptune Pluto		excluded because irregularities in orbits make it impossible to calculate percent of error.

24. 271,398 astronomical units

25. 2.524×10^{10} miles

26.	Explorer VII	(a)	508.5 miles	(b)	818.7 kilometers
	Echo I	(a)	997 miles	(b)	1,605 kilometers
	Orbiting Solar Observatory (OSO)	(a)	356.2 miles	(b)	573.5 kliometers
	Explorer XIV	(a)	30,682.1 miles	(b)	49,398.2 kilometers
	Relay I	(a)	2,709.4 miles	(b)	4,370.0 kilometers
	Syncom II	(a)	22,194.9 miles	(b)	35,798.2 kilometers
	TIROS VIII	(a)	451 miles	(b)	728 kilometers

27. (a) 381,709 kilometers, (b) 0.00255 astronomical units
28. 43.73 astronomical units
29. 11,500 kilometers
30. yes
31. e = 0.988
32. e = 0.104
33. low eccentricity
34. e = 0.029
35. e = 0.037
36. low
37. e = 0.0002158 round off to e = 0.000216
38. All distances in astronomical units (does not include eccentricity)

Planets	Perihelion distance	Aphelion distance	Average distance	(c)	Eccentricity
Mercury	0.3076	0.4666	0.3871	0.0795	0.206
Venus	0.7182	0.7284	0.7233	0.0051	0.007
Earth	0.9830	1.0170	1.0000	0.0170	0.017
Mars	1.3820	1.7654	1.5237	0.1417	0.093
Ceres	2.5542	2.9804	2.7673	0.2131	0.077
Jupiter	4.9531	5.4525	5.2028	0.2497	0.048
Saturn	9.0051	10.0735	9.5393	0.5242	0.056
Uranus	18.2814	20.0846	19.1830	0.9016	0.047
Neptune	29.7812	30.3342	30.0577	0.2765	0.009
Pluto	29.6800	49.3576	39.5177	9.8399	0.249

39. v = 5,000 miles/sec.
40. v = (a) 308.7 miles/minute, (b) 5.1 miles/sec., (c) 8.2 kilometers/sec.
41. v = (a) 25,085 kilometers/hour, (b) 7 kilometers/sec. approximately
42. v = (a) 186,000 miles/sec., (b) 299,460 kilometers/sec.
43. d = (a) 5,869,714,600,000 miles, (b) 9,450,240,506,000 kilometers, (c) 63,115.22 astronomical units
44. Diameter of Milky Way = 100,000 light years
45. d = 4.3 light years
46. d = 255,135 kilometers
47. d = 744,000 miles = 1,197,840 kilometers
48. d = 15.5 light years
49. t =500 sec. = 8⅓ minutes
50. t = 4,770 sec. = 79½ minutes
51. t = 1.27 sec.
52. t = 500 sec. = 8⅓ minutes (same as for visible light)

53. (a) 2446 B.C., (b) 3,500 light years away (the answers to this question are based on the year A.D. 1964)

54. 65,000 light years

55. Gamma radiation has high frequency and radiowave radiation has low frequency. Radiowave radiation has long wave lengths so it takes longer for one wave length to pass a given point than it does for one wave length of shorter wave length radiation.

56. frequency range = 7,486,500,000,000,000 (purple or violet light) to 4,278,000,000,000,000 (red light) cycles/sec.

57. $\lambda = 1.29$ meters

58. $\lambda =$ (a) 1,657 to 1.657 centimeters, (b) 16.57 to 0.01657 meters, (c) 54.35 to 0.05435 feet

59. f = 110,911,000,000 cycles/sec. = 110,911. megacycles (a megacycle is a million cycles/sec.)

60. change in wave length = 0.000002525 meter

61. $\lambda = 0.003497475$ meter

62. v = 124.78 kilometers/sec.

63. v = 74,865 kilometers/sec.

64. (a) 1 centimeter = 100,000,000 angstrom units (b) 1 meter = 10,000,000,000 angstrom units

65. v = (a) 43 miles/sec., (b) 69 kilometers/sec.

66. v = (a) 2.4 kilometers/sec., (b) 1.5 miles/sec., (c) 8,640 kilometers/hour, (d) 5,400 miles/hour

67. t = 1 when d = 16 feet   t = 3 when d = 144 feet
t = 2 when d = 64 feet   t = 4 when d = 256 feet

68. t = 8 sec.

69. a = 444.4 feet/sec.^{2} approximately.

70. t = 11.2 sec. (down)

71. t = 16.53 sec.

72. v = 358.4 feet/sec.

73. v = 158.7 meters/sec.

74. (a) t = 40.24 sec., (b) d = 338 meters

75. (a) 980 centimeters/sec.^{2}, (b) 9.8 meters/sec.^{2}

76. a = 274.40 meters/sec.^{2}

A SELECTED BIBLIOGRAPHY

Ahnstrom, D. N. *The Complete Book of Jets and Rockets.* Yonkers, New York: World, 1959.

Asimov, Isaac. *Satellites In Outer Space.* New York: Random, 1960.

Beauchamp, Wilbur L., et al. *Science is Explaining.* Chicago: Scott Foresman and Company, 1963.

Bondi, Hermann. *The Universe at Large.* New York: Doubleday and Co., Inc., 1960.

Boyd, R. L. F. *Space Research by Rocket and Satellite.* New York: Harper, 1960.

Brinley, Bertrand R. *Rocket Manual for Amateurs.* New York: Ballantine, 1960.

Burgess, Eric. *Satellites and Spacecraft.* New York: Macmillan, 1958.

Butler, S. T. and H. Messel. *The Universe of Time and Space.* New York: Macmillan Co., 1963.

Cox, Donald, and Michael Stoiko. *Rocketry Through the Ages.* New York: Winston, 1959.

Davis, Clive E. *Messages from Space.* New York: Dodd Mead, 1961.

Dietz, David. *All About Satellites and Space Ships.* New York: Random, 1958.

Dull, Charles E., et al. *Modern Physics.* New York: Holt, Rinehart, and Winston, Inc., 1961.

Elliott, L. Paul and William F. Wilcox. *Physics—A Modern Approach.* New York: Macmillan Company, 1959.

Fermi, Laura and Gilberts Bernardini. *Galileo and the Scientific Revolution.* New York: 1961.

Gamow, George. *Gravity.* New York: Doubleday and Co., Inc., 1962.

Gardner, Martin. *Science Puzzlers.* New York: Viking, 1960.

Gottlieb, William. *Jets and Rockets and How They Work.* New York: Garden City, 1959.

Haley, Andrew G. *Rocketry and Space Exploration.* Princeton, New Jersey: Van Nostrand, 1958.

Hogben, Lancelot. *The Wonderful World of Mathematics.* New York: Doubleday, 1955.

James G. S. *Rocket Building for Students.* New York: Rocket Research Institute, 1958.

Joseph, Alexander, Paul F. Brandwein, et al. *A Source-book for the Physical Sciences* (Demonstrations on pages 366-371). New York: Harcourt, Brace, and World Inc., 1961.

Knight, Clayton. *The How and Why Wonder Book of Rockets and Missiles.* New York: Grosset, 1960.

Knight, Clayton. *Rockets, Missiles, and Satellites.* New York: Grosset, 1958.

Landau, D. L. *What is Relativity* (Translation from Russian. Moscow: 1959). New York: Basic Books Inc., 1959.

Ley, Willy. *Rockets, Missiles, and Space Travel.* New York: Viking, 1961.

Mark, David. *All About Missiles and Satellites.* Cowan, 1959.

Mehrens, H. E. *The Dawning Space Age.* Civil Air Patrol, 1959.

Munch, Theodore W. *What Is a Rocket.* Chicago: Benefic, 1959.

Munroe, Kenneth. *A Guide to Understanding Jets, Rockets, and Satellites.* New York: Walch, 1961.

Murchie, Guy. *Music of the Spheres* (First half of Chapter 10). Cambridge, Mass.: Riverside Press, 1961.

NASA and U.S. Office of Education. *What's Up There* (144 page paperback on space science oriented mathematics). Washington: Government Printing Office, 1964.

Neurath, Marie. *Man-Made Moons.* New York: Lothrop, 1960.

Neurath, Marie. *Rockets and Jets.* New York: Lothrop, 1960.

Newell, Homer E. *Express to the Stars.* New York: McGraw-Hill, 1961.

Newell, Homer E. *Guide to Rockets, Missiles and Satellites.* New York: Whittlesey House, 1958.

Ovenden, Michael W. *Artificial Satellites.* Baltimore: Penguin, 1961.

Parker, Bertha Morris. *Rockets and Missiles.* Evanston, Illinois: Row Peterson, 1961.

Parkin, Charles M., Jr. *The Rocket Handbook for Amateurs.* New York: Day, 1959.

Physical Science Study Committee (P.S.-S.C. Text). *Physics,* (Chapter 5). Boston: D. C. Heath and Co., 1960.

Pratt, Fletcher. *All About Rockets and Jets.* New York: Random, 1958.

Rogers, Eric M. *Physics for the Inquiring Mind* (Chapter 1 on Gravity, Interlude—Appendix on Arithmetic, page 193, and chapter 19 on Galileo). Princeton, N.J.: Princeton University Press, 1960.

Rosen, Sidney. *Galileo and the Magic Numbers.* Boston: Little, Brown and Company, 1958.

Ruchlis, Hy. *Orbit*. New York: Harper and Brothers, 1958.

Sargeant, Charles. *How to Draw Rockets and Spaceships*. New York: Viking, 1958.

Sharp, Elizabeth N. *The Science Book-Lab of Jet Engines*. New York: Basic, 1961.

Stine, G. Harry. *Rocket Power and Space Flight*. New York: Holt, Rinehart and Winston, 1957.

Taylor, John W. R. *Rockets and Satellites Work Like This*. New York: Roy, 1959.

Trinklein, Frederick E. and Charles M. Huffer. *Modern Space Science*. New York: Holt, Rinehart, and Winston, Inc., 1961.

United Nations Educational, Scientific and Cultural Org. *UNESCO Source Book for Science Teaching* (Chp. XI, section B, Experiments with Gravity). Paris: UNESCO, 1962.

Wiech, Raymond E., Jr., and Robert F. Strauss. *Fundamentals of Rocket Propulsion*. New York: Reinhold, 1960.

THE
SPACE
ENVIRONMENT

INTRODUCTION

Each unit deals with one aspect of space environment and contains a list of references in case the reader wishes to study the subject further.

The Earth's Atmosphere

The NASA-sponsored U. S. Standard Atmosphere, 1962 has furnished the major portion of the material for this unit. Marginal graphs show average values of atmospheric pressure, density, and kinetic temperature for all altitudes to 700 km. The paragraphs on atmospheric composition present the concentrations of both the neutral and ionized molecules. This unit concludes with probability contours for the extreme wind conditions over the United States, abstracted from design data recommendations in the U. S. Air Force Handbook of Geophysics.

The Structure of the Ionosphere

Photoionization results in the formation of distinct regions of electron concentrations in the upper atmosphere which are known as the ionosphere. This unit describes the characteristics of these regions, including the numerous variations in electron densities as to time and what is known of causal and accompanying phenomena.

Solid Particles

This unit describes the types of solid particles and their distribution in atmosphere and space. Recent satellite experiments and ground observations form the basis for current thought on this subject.

Energetic Particles

This unit deals with the atomic and subatomic matter found in space. Although negligible in size, these particles have dangerously high energies. The introductory figure plots the flux of the various particles as a function of their energy. The major classifications--cosmic rays, particles of solar origin, and particles trapped near earth--are easily seen on this plot, as is the fact that particles of cosmic origin have the highest energies, while the trapped particles exhibit the greatest intensities.

Electromagnetic Radiation

This phenomenon arises from two major sources: the sun and the earth. The unit incorporates recent data obtained by the Tiros satellites in a review of current knowledge.

Magnetic Fields

This unit discusses the intensities and variations of the magnetic fields which exist at the surface of the earth, in the atmosphere, ionosphere, magnetosphere, and interplanetary space. Evidence from experiments carried by deep space probes forms the basis for estimates of the magnetic field strength in interplanetary space.

For the contribution of their judgment and time in review of the various units we are most grateful to R. E. Bourdeau, Dr. W. Nordberg, W. M. Alexander, Dr. C. E. Fichtel, H. H. Malitson, and Dr. J. P. Heppner, all of Goddard Space Flight Center.

EARTH'S ATMOSPHERE

The earth's atmosphere is a gaseous envelope surrounding the earth and extending outward to where the kinetic velocity of the atmospheric particles overcomes gravitational forces at distances from one-half to one earth radius from the earth's surface. At altitudes up to 90 km the atmosphere is a stable, homogeneous mixture, consisting mainly of nitrogen and oxygen molecules in the ratio of about 4 to 1. Above 90 km the diffusion process becomes more important than the mixing process, and the various atmospheric constituents tend to concentrate at various levels in atomic form with oxygen (having the highest atomic weight) concentrating at lower levels and the other elements tending to concentrate at successively higher levels in order of decreasing atomic weight. An added complexity in the atmospheric composition above 90 km results from the dissociation and ion production induced by solar radiation; below this altitude the atmosphere consists mainly of neutral molecules while at higher altitudes the concentration of ionized particles is significant.

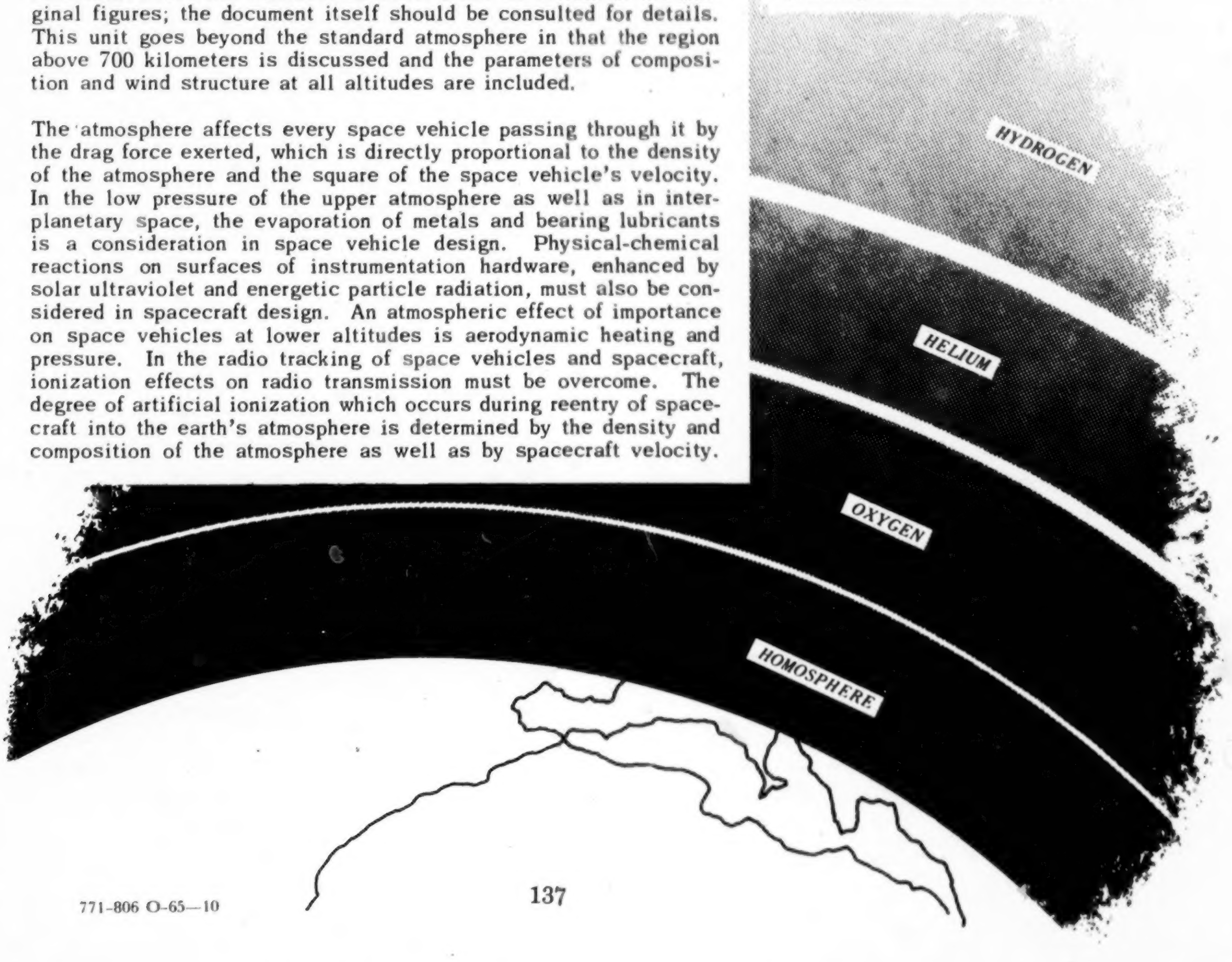
Atmospheric parameters of major interest are the pressure, temperature, density, composition, and wind structure as a function of altitude. Up to 700 kilometers altitude, the best existent summary of pressure, temperature, and density, and variations therein (some estimated) is the 1962 version of the U. S. Standard Atmosphere. Temperature, pressure, and density data from the new standard are summarized for some altitudes in Table I and on certain of the marginal figures; the document itself should be consulted for details. This unit goes beyond the standard atmosphere in that the region above 700 kilometers is discussed and the parameters of composition and wind structure at all altitudes are included.

The atmosphere affects every space vehicle passing through it by the drag force exerted, which is directly proportional to the density of the atmosphere and the square of the space vehicle's velocity. In the low pressure of the upper atmosphere as well as in interplanetary space, the evaporation of metals and bearing lubricants is a consideration in space vehicle design. Physical-chemical reactions on surfaces of instrumentation hardware, enhanced by solar ultraviolet and energetic particle radiation, must also be considered in spacecraft design. An atmospheric effect of importance on space vehicles at lower altitudes is aerodynamic heating and pressure. In the radio tracking of space vehicles and spacecraft, ionization effects on radio transmission must be overcome. The degree of artificial ionization which occurs during reentry of spacecraft into the earth's atmosphere is determined by the density and composition of the atmosphere as well as by spacecraft velocity.

TABLE I

HEIGHT (KM)	TEMP °K	PRESSURE* (MB)	DENSITY* kg m -3
0.000	288.15	10.1325 + 2*	1.2250 0
11.019	216.65	2.2632 + 2	3.6392 - 1
20.063	216.65	5.4747 + 1	8.8035 - 2
32.162	228.65	8.6798 0	1.3225 - 2
47.350	270.65	1.1090 0	1.4275 - 3
52.429	270.65	5.8997 - 1	7.5943 - 4
61.591	252.65	1.8209 - 1	2.5109 - 4
79.994	180.65	1.0376 - 2	2.001 - 5
90.000	180.65	1.6437 - 3	3.170 - 6
100.000	210.02	3.0070 - 4	4.974 - 7
110.000	257.00	7.3527 - 5	9.829 - 8
120.000	349.49	2.5209 - 5	2.436 - 8
150.00	892.79	5.0599 6	1.836 - 9
160.000	1,022.20	3.6929 - 6	1.159 - 9
170.000	1,103.40	2.7915 - 6	8.036 - 10
190.000	1,205.40	1.6945 - 6	4.347 - 10
230.000	1,322.30	6.9572 - 7	1.564 - 10
300.000	1,432.10	1.8828 - 7	3.585 - 11
400.000	1,487.40	4.0278 - 8	6.498 - 12
500.000	1,499.20	1.0949 - 8	1.577 - 12
600.000	1,506.10	3.4475 - 9	4.640 - 13
700.000	1,507.60	1.1908 - 9	1.537 - 13

**Terminal number indicates power of 10 by which preceding number must be multiplied.*



Pressure, Temperature, and Density

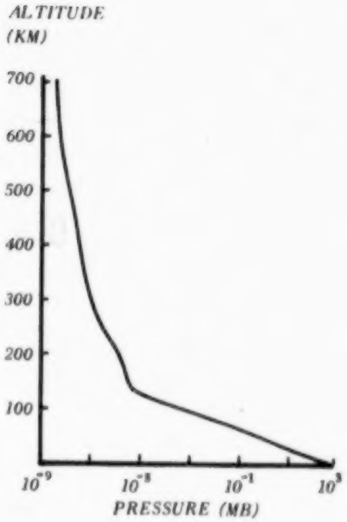
Table I has been extracted from the U. S. Standard Atmosphere, 1962; the entries describe the idealized middle latitude, year-round mean of three atmospheric parameters over the range of solar activity. These means are more valid for the lower levels of the atmosphere where actual observations are more numerous. A distinction is, in fact, made in the referenced document. Tabulated values for the region below 32 kilometers are considered 'standard;' values for the 32–90 kilometer range are 'proposed standard,' while values above 90 kilometers are described as 'speculative.'

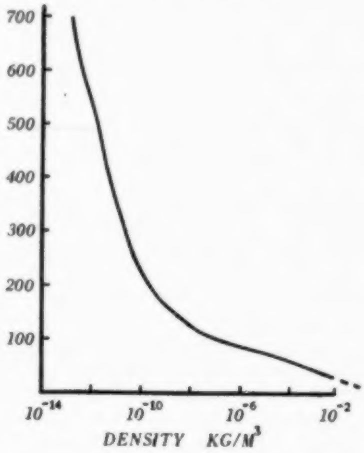
The parameters for the region below 90 kilometers have been sufficiently observed that latitudinal and seasonal variations may be distinguished. A detailed presentation of these variations for four latitudes and two seasons will soon be available as supplements to the 1962 standard atmosphere. Variations accompanying change in latitude or season in the region below 90 kilometers may, however, be briefly described as follows. It is estimated that density variations range from a low of about 1 percent of the Table I value at 8 kilometers to a high of about 50 percent near 70 kilometers. Temperature variations range from 4 to 30 percent around the tabulated values. Density variations at 90 km are probably less than at 70 km but increase rapidly above 90 km.

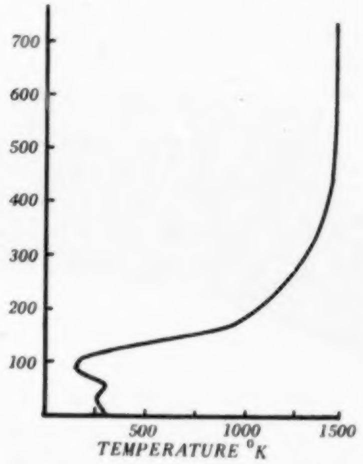
Data are insufficient to define mean values of temperature, pressure, and density parameters for various seasons or latitudes in the 90 to 200 km altitude range; the standard atmosphere values are means of the existing measurements.

One of the recent results of the space program is the finding that there are considerable variations in temperature, pressure, and density above 200 km. These variations have been directly related to solar radiation. A diurnal variation in temperature in the order of 500 degrees K may occur in the region from 200 to 700 km. This temperature fluctuation causes diurnal density variations up to one order of magnitude above the temperature variation at these altitudes. Consistent with the strong correlation between density/temperature fluctuations and solar radiation in the diurnal cycle, fluctuations in density and temperature occur in a seasonal pattern and also in response to solar activity.

It should be noted that the atmosphere at a given time is nearly isothermal above 300 km. Temperature in these regions is usually deduced from density measurements determined from satellite drag observations.



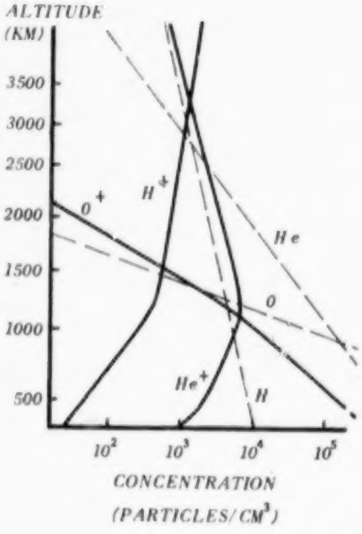




Composition

Up to 90 kilometers altitude, the atmosphere is a homogeneous mixture largely of molecular nitrogen (78.08 percent) and oxygen (20.95 percent). Argon and carbon dioxide contribute 0.93 and .03 percent respectively. The trace elements include, in order of decreasing content, the following: neon, helium, krypton, xenon, hydrogen, methane, nitrous oxide, ozone, sulfur dioxide, nitrogen dioxide, ammonia, carbon monoxide, and iodine. Water vapor is present in increasing concentration towards the ground and ozone becomes an important trace element from 20 to 70 kilometers.

Above 90 km the atmospheric constituents tend to concentrate at differing altitudes in atomic form with elements of higher atomic weight predominating at lower altitudes and those of lower atomic weight concentrating at higher altitudes. Thus oxygen is the predominant component from 200 to 1000 kilometers, helium from 1000 to 3000 kilometers, and hydrogen at altitudes above 3000 kilometers. An increasing proportion of the atoms and molecules above 90 km are ionized with approximately one-half of all constituents being ionized near 1500 km.

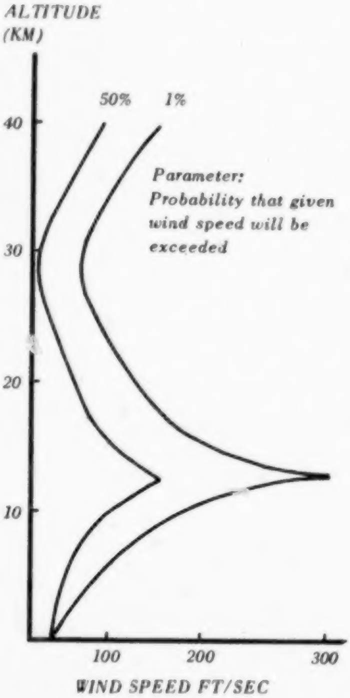


Winds

The wind structure of the atmosphere, particularly below 90 km, is a function of locale and time; a detailed prediction can generally be extrapolated only for a brief time period following the measurement of existing conditions. Statistical summaries are available for both world wide and local areas, and data are often available for inclusion in summaries for new areas of interest. Such data, however, exist only within the range of balloon measurements (up to 30 km). The material below presents what are the extreme conditions expected over the United States, considering altitudes up to 30 km.

In the winter and over the windiest area of the United States the strongest winds in this altitude range occur between 9 and 12 kilometers altitude. The marginal figure shows the speed profile expected to be exceeded at various probabilities. A speed of 300 feet per second will be exceeded only one percent of the time in the 9–12 kilometer region; the minimum at greater altitudes and the same probability occurs near 24 kilometers and has a value of about 80 feet per second. Available data have also been accumulated and estimates may be made of the probability that the expected wind falls within any range of directions.

Wind data for the region above 30 km are limited. The winds blow generally from east or west directions, and a maximum occurs in all seasons at altitudes from 50 to 60 km. Much higher winds than at lower altitudes have been observed in the 50 to 60 km region and above. These high wind velocities are mainly important, however, in their effect upon atmospheric circulation and do not present a serious problem to space vehicles because the force represented by high winds at these altitudes is relatively small because of low atmospheric density.



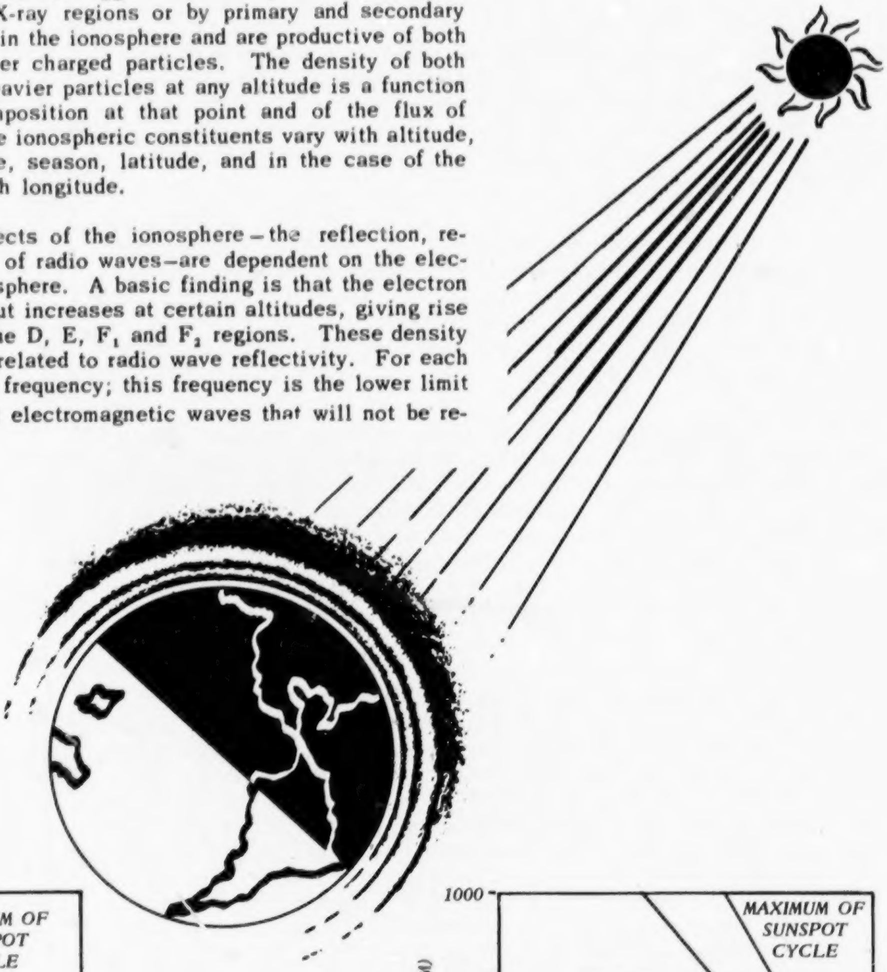
Parameter: Probability that given wind speed will be exceeded

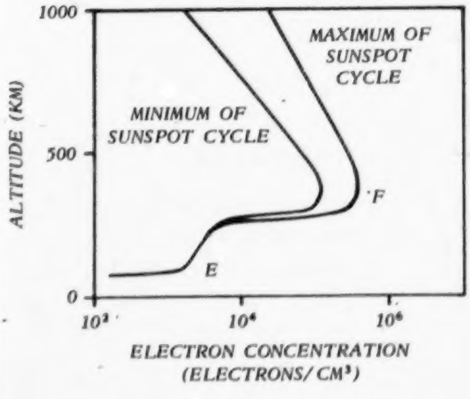
STRUCTURE OF THE IONOSPHERE

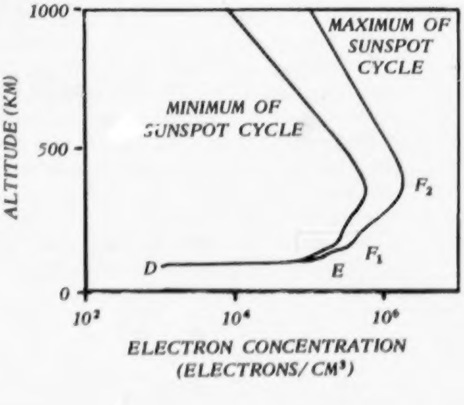
The ionosphere, an atmospheric region characterized by the presence of ionized atmospheric constituents, forms a spherical shell around the earth which begins at approximately 50 kilometers above the surface. If the term is restricted to its older sense, then the upper boundary of the ionosphere is the altitude at which radiosounding techniques become ineffective (about 300 kilometers). This region is, however, under extensive study by satellites and rockets, and research has already shown that the upper boundary is indefinite and that the region extends to the interplanetary plasma.

Various ionization reactions, triggered either by solar radiations in the ultraviolet and X-ray regions or by primary and secondary cosmic rays, take place in the ionosphere and are productive of both electrons and the heavier charged particles. The density of both the electrons and the heavier particles at any altitude is a function of the atmospheric composition at that point and of the flux of radiant energy. Thus the ionospheric constituents vary with altitude, time of day, solar cycle, season, latitude, and in the case of the classical F_2 region, with longitude.

The most important effects of the ionosphere – the reflection, refraction, and absorption of radio waves – are dependent on the electron density of the ionosphere. A basic finding is that the electron density is not uniform but increases at certain altitudes, giving rise to what are known as the D, E, F_1 and F_2 regions. These density maxima can be directly related to radio wave reflectivity. For each layer there is a critical frequency; this frequency is the lower limit to the normally incident electromagnetic waves that will not be reflected by the layer.







D Region

The region of the ionosphere nearest the earth is the D region. Normally it is situated within the altitude range of 50 to 85 kilometers. The D region absorbs radio waves of interest but not so extensively as to reflect or severely refract, as occurs in the E and F regions.

Ionization in the D region is generated principally by Lyman alpha radiation, cosmic rays, and X-rays. There is general agreement that cosmic radiation is the dominant feature in lower D region ionization. In the upper D region the principal ionizing radiation is thought to be, normally, Lyman alpha radiation; the resulting ions being predominantly nitric oxide and molecular oxygen. Shortly after certain solar disturbances, hard X-ray (below 8 angstrom units) fluxes increase to high enough levels to become the principal cause of ionization.

The resulting D region electron concentrations are not easily measured by land-based ionospheric sounding techniques. However, limited data obtained by land-based methods and rocket flights are consistent with an approximate figure for the peak electron concentration of 1000 electrons per cubic centimeter occurring near an altitude of 80 kilometers.

Diurnal and solar cycle effects produce the largest variations in the D region electron densities. The D region is predominantly a daytime phenomenon. During the hours of darkness it all but disappears, except under conditions of increased solar activity. It is thought that the disappearance of the D region at night is caused by recombination of the free electrons with either positive ions or neutral particles. Regardless of the phenomenon, the end result is a decrease in the absorption of radio waves as compared with daylight hours.

Certain types of solar flares are responsible for three types of absorption anomalies and for increases in concentration by as much as two orders of magnitude. The Type I phenomenon occurs at the same time as the solar flare, but only in the sunlit portion of the ionosphere. It is called a sudden ionospheric disturbance (SID) and usually lasts approximately half an hour. The resultant radio blackout is thought to be caused by increased ionization of the lower D region by X-rays emitted from the sun during the flare. The second or Type II phenomenon is associated with aurorae and local magnetic disturbances and takes place mainly at night. Though it is more intense in nature at higher latitudes, it has been observed outside the auroral zone. The enhanced radio wave absorption during these events is thought to be due to an increased ionization from solar particle emission. Polar cap blackouts of the Type III phenomenon occur principally above the auroral zones. These events occur a few hours after a solar flare and can persist for a number of days; their effects are more noticeable during the daylight hours. As might be expected, the occurrence of the above phenomena is closely related to the 11-year sunspot cycle.

IONOSPHERE
D REGION

LOCATION

50 – 85 KM

PRINCIPAL IONIZING RADIATION

LYMAN α

X–RAYS

COSMIC RAYS

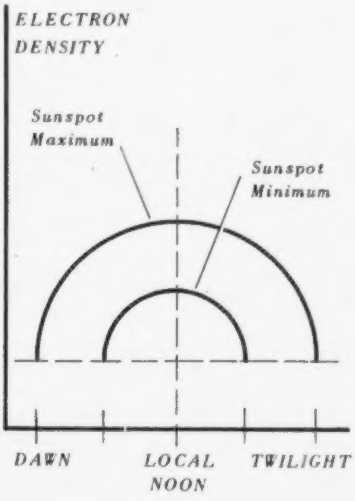
PRINCIPAL IONS

NO^+ O_2^+

ELECTRON CONCENTRATION AT PEAK

~10^3 ELECTRONS/ CM^3 AT 80 KM

MAJOR VARIATIONS



ANOMALIES

INCREASED IONIZATION FOLLOWING SOLAR FLARE ACTIVITY

E Region

Between 85 and 140 kilometers altitude lies the second or E region. Ionization in the E region is generated principally by solar radiation in the ultraviolet range (170–1027A) and by soft X-rays. Recent data, showing that the ultraviolet intensities are two orders of magnitude greater than formerly believed, have been interpreted to mean that the ultraviolet is the more important radiant. The ionization of molecular oxygen by ultraviolet radiation determines the electron content in region E. Other ions thought to be present in varying quantities are nitric oxide and monatomic oxygen.

Electron densities in the E region obtained from theoretical models as well as by experimental methods are in quite good agreement. Concentrations of approximately 150,000 per cubic centimeter are typical for local noon at sunspot minimum and at 105 kilometers, a typical height for the density maximum.

Diurnal, seasonal, latitudinal, and solar cycle variations of electron densities in the E region occur with a relatively high degree of predictability. The diurnal variation of electron densities is large with the maximum occurring at local noon. The seasonal variation is symmetrical about a maximum occurring during the local summer months. The higher latitudes, though having lower mean densities throughout the year, have a much greater overall change from summer to winter than the lower latitudes. Variations of concentration due to solar activity can amount to an increase of approximately 50 percent from sunspot minimum to sunspot maximum.

The irregular occurrence of relatively dense concentrations of electrons in the E region at altitudes near 100 kilometers is an anomaly called Sporadic E. Sporadic E densities are roughly twice those in the layer proper. There does not appear to be any correlation between the solar variation and Sporadic E except that the anomalous concentrations occur near the magnetic equator during daylight hours and at higher latitudes at night. In the temperate latitudes Sporadic E occurs much more often in the summer months than in the other seasons. It is thought that Sporadic E is caused by the appearance of localized regions of increased ionization in the main E region and not by increased ionization of the layer proper.

F Region

The third and highest of the ionospheric regions is the F region. During part of each day, it is actually two regions, denoted as the F_1 and F_2 regions with the F_2 region more distinct than the F_1. Throughout the remaining hours, between sunset and sunrise, the F_1 region disappears.

Ionization in the F region is caused principally by solar radiation in the ultraviolet range (170–911 angstrom units). The predominant ions formed are molecular oxygen and nitric oxide in the lower F_1 region, changing to principally monatomic oxygen in the upper F_1 and lower F_2 regions. Monatomic oxygen is the predominant ion to about 1000 kilometers for high levels of solar activity. Recent space experiments have

IONOSPHERE
E REGION

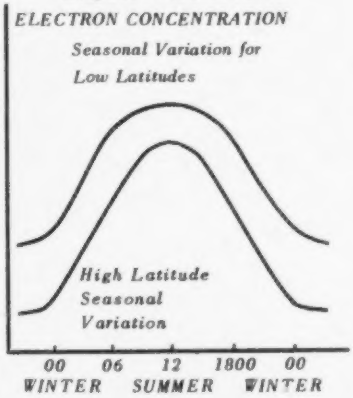
LOCATION – 85-140 KM

PRINCIPAL IONIZING RADIATION
ULTRAVIOLET • SOFT X-RAYS

PRINCIPLE IONS
(O_2^+) (NO^+) (O^+)

ELECTRON CONCENTRATION AT PEAK
1.5×10^5 ELEC
CM^3 AT 105 KM

MAJOR VARIATIONS



ANOMALIES

SPORADIC E - LOCALIZED REGIONS OF APPROXIMATELY TWICE THE NEARBY LAYER DENSITY APPEAR; IONIZATION MECHANISM NOT KNOWN

IONOSPHERE
F REGION

LOCATION
ABOVE 140 KM
WITH TWO LAYERS
F_1 AND F_2 OBSERVED

PRINCIPAL IONIZING RADIATION
ULTRAVIOLET

shown that helium ions predominate in a layer of variable thickness above 1000 kilometers. At higher altitudes, hydrogen ions predominate.

Electron concentrations in the F region rise to a maximum between 300 and 375 kilometers and then taper off to the relatively low levels found in space beyond the ionosphere. In the F_1 region a typical noon sunspot minimum value for the electron concentration is approximately 250,000 per cubic centimeter at 170 kilometers. Electron concentrations in the F_2 region reach a maximum on the order of one million per cubic centimeter at approximately 320 kilometers. The electron concentrations in the F region are highly variable; the variations being a function of diurnal, seasonal, latitudinal, solar cycle, and, for the F_2 region, longitudinal effects.

F_1 Region

The F_1 region variations are as a rule much more predictable than those of the F_2 region. The diurnal variation of the F_1 electron densities is generally symmetrical about the local noon maximum during the hours of daylight. At night the densities fall below those measurable by ionosondes (approximately 10,000 per cubic centimeter), and the F_1 region becomes indistinguishable from the F_2 region. The seasonal and latitudinal variations of the F_1 region are also directly related to the zenith angle of the sun, the average local noon maxima for each month being symmetrical about the summer solstice. Concentrations throughout a solar cycle will change by a factor of about 1.75 from sunspot minimum to sunspot maximum.

F_2 Region

The F_2 region variations are complex; variations with longitude as well as solar and latitude effects occur.

The diurnal variation has two major characteristics:

(a) The change in electron densities at sunrise and sunset is more abrupt than that in the other ionospheric regions.

(b) In mid latitudes during the winter months daily variations in density tend to be symmetric, with the maximum lagging noon by about two hours; but at other geographical positions and during other seasons the density-time function has two maxima, one before noon and one after. There are other complexities of somewhat lesser importance.

Latitude and seasonal variations are not easily summarized. In general, values of the electron density for latitudes between 50 degrees north and 35 degrees south tend to be higher than average during November, December and January.

There is a gradual increase in electron density from quiet to active sun condition.

All of these variations in density are accompanied by a variation in F_2 region height. The height is greater at night in the equatorial region and increases with increasing solar activity.

PRINCIPAL IONS

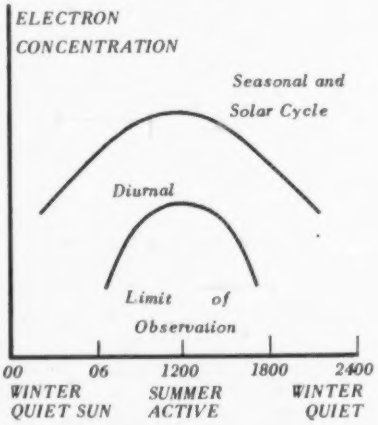
LOWER REGION	O_2^+ NO^+
MIDDLE REGION	O^+
UPPER REGION	He^+ H^+

ELECTRON CONCENTRATION

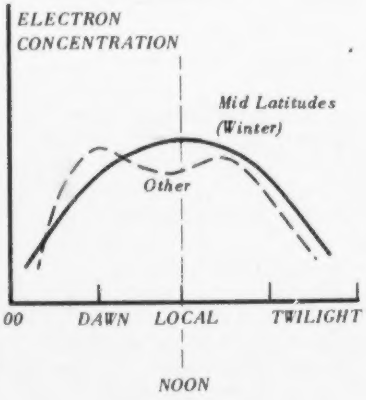
2.5 X 10^5 ELECTRONS/CM^3
AT 170 KM (F_1)

10^6 ELECTRONS/CM^3
AT 320 KM (F_2)

MAJOR VARIATIONS
F_1 LAYER



MAJOR VARIATIONS
F_2 LAYER



The major anomaly is the appearance, usually at night, of regions of higher electron densities. This gives rise to a multiplicity of returns to sounding apparatus, hence the term Spread F used in reference to this phenomenon. The frequency of occurrence varies from rare occurrences at 35 degrees geomagnetic to greater frequencies at high latitudes with a quiet sun. In temperate latitudes, Spread F tends to be associated with magnetic disturbances. Recent rocket sounding experiments also indicate a dependence of Spread F on the magnetic field; the multiple returns were believed the result of field guided ducting along magnetic field aligned irregularities. Preliminary data from Ariel and Alouette satellites indicate that irregularities are associated with the Van Allen radiation belts.

VARIATIONS NOT PICTURED

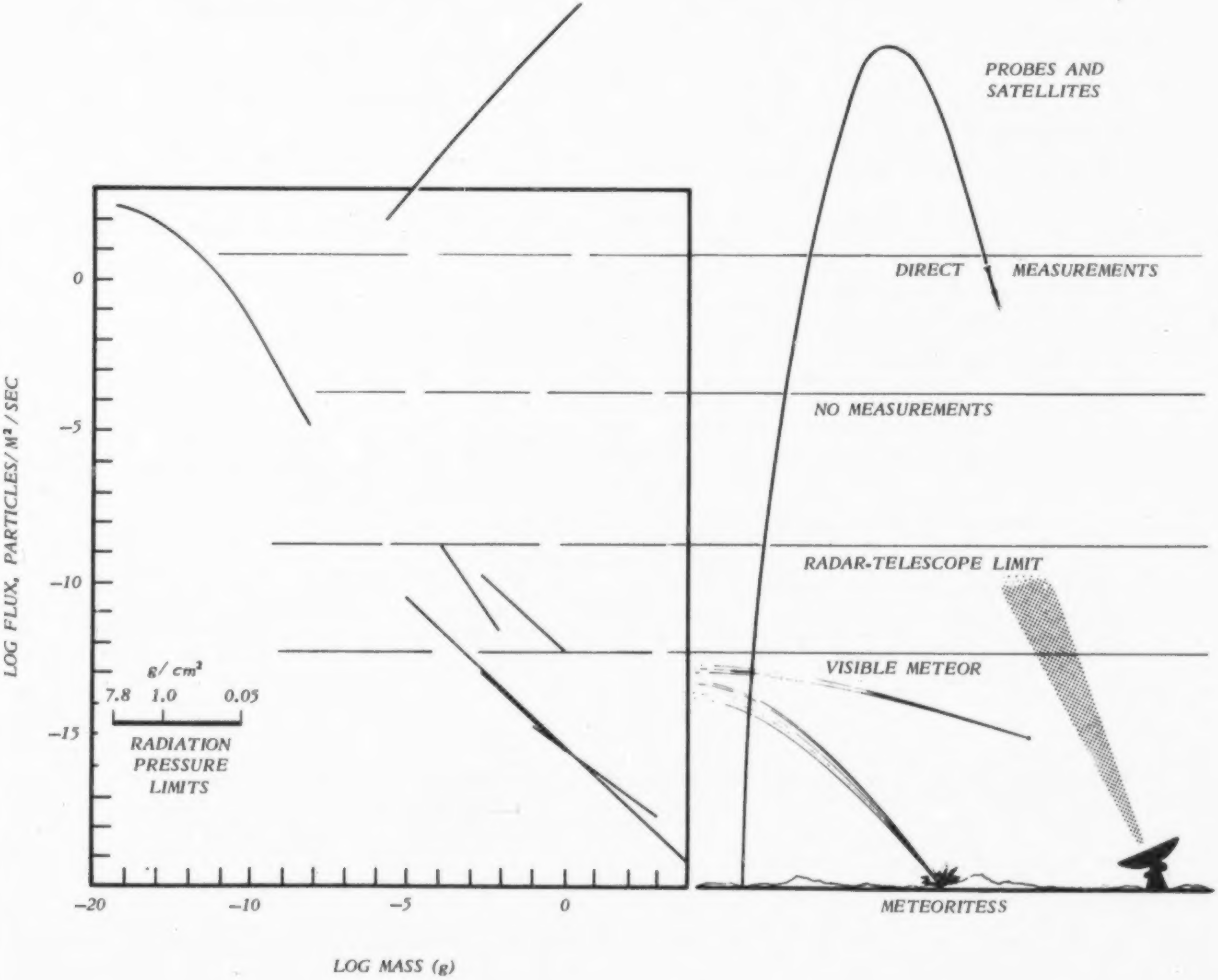
1) *ABRUPT CHANGES AT SUNRISE AND SUNSET*
2) *LATITUDE AND SEASONAL VARIATIONS*
3) *INCREASE WITH ACTIVE SUN*
4) *HEIGHT VARIATIONS*

SOLID PARTICLES

It has long been recognized that meteors are evidence that space must contain solid particles. Study and deduction, particularly that based on visual observations of meteors, has resulted, for the larger particles, in magnitude estimates of the important parameters: the size, density, velocity, flux and spatial distribution. Currently, study of the collisions of the smaller particles with instrumented portions of satellites is adding significantly to existing knowledge.

The solid particles are from one of two sources, comets or asteroids. Ninety percent of the particles found in space are estimated to be of cometary origin.

The principal effect of the solid particles on space vehicles is not structural failure but rather the degradation of the exposed surfaces, particularly those of sensitive instrumentation. Mass-to-flux relationships obtained to date indicate that damage from puncture is secondary to the erosion hazard.



Physical Characteristics

The solid matter landing on the earth falls into three categories: the iron meteorites (densities 7–8 grams per cubic centimeter), the more numerous stone meteorites (densities 3–4 grams per cubic centimeter), and the 'dust balls' (densities 0.1–2.0 grams per cubic centimeter.) Estimates of mean velocity with respect to the earth range from 15 to 43 kilometers per second, with 30 kilometers per second often used in computations when a single representative value is required. The preponderance of the solid particles is believed to be small (1–100 microns in diameter); particles in this size range are collectively referred to as the interplanetary dust. The bulk of the interplanetary dust is concentrated near the plane of the ecliptic and the separate particles are, as is the earth, in direct, rather than retrograde, orbit around the sun.

There is known to be considerable variation in the physical parameters. There is a lower limit to size imposed by radiation pressure from the sun which sweeps particles smaller than about one micron in diameter from the solar system. There is no definite upper limit to size; bodies many miles in diameter are known to exist. The lower limit to velocity, relative to the earth, is 11 kilometers per second, the velocity acquired by a falling particle initially at rest with respect to the earth.[1] The upper limit, 72 kilometers per second, is obtained by adding the earth's orbital velocity to the velocity a particle would need to escape the solar system from an orbit about the sun at one astronomical unit.

Recent satellite experiments have been designed to measure the solid particle flux (the number of encounters per unit area per unit time) for particles too small to produce a meteor detectable by visual, optical, or radar techniques. As shown in the introductory figure, the measured flux of the smaller particles prove to be greater than would be expected by extrapolation of the older data. Of particular interest, therefore, will be those future studies of the flux in the yet unknown region between the two sets of data. Finally, the introductory figure shows what is called the sporadic, or average, particle flux. Meteor showers are a well known and often occurring phenomenon and flux rates at a shower peak can rise to values which are four or five times the sporadic rate.

The concentration of the greater bulk of the solid material, i.e., the interplanetary dust, in the plane of the ecliptic has been noted. Deductions based on observations of the zodiacal light indicate that the dust concentration is highest near the sun and that the concentration diminishes roughly in inverse proportion to the three halves power of the distance from the sun. There is some evidence that the concentration may be slightly elevated in the immediate vicinity of the earth.

SOLID PARTICLES

TYPES AND DENSITIES

IRON	*7–8 GM/CM^3*
STONE	*3–4 GM/CM^3*
DUST BALLS	*.1–2 GM/CM^3*

MEAN VELOCITY

30 KM/SEC

SIZE RANGE

1 MICRON TO MANY MILES

VELOCITY RANGE

11 KM/SEC – 72 KM/SEC

VARIATIONS

1) FLUX RATES 4 or 5 TIMES HIGHER DURING METEOR SHOWERS

2) CONCENTRATION IS HIGHER BOTH IN THE PLANE OF THE ECLIPTIC AND IN THE REGIONS NEAR THE SUN

---

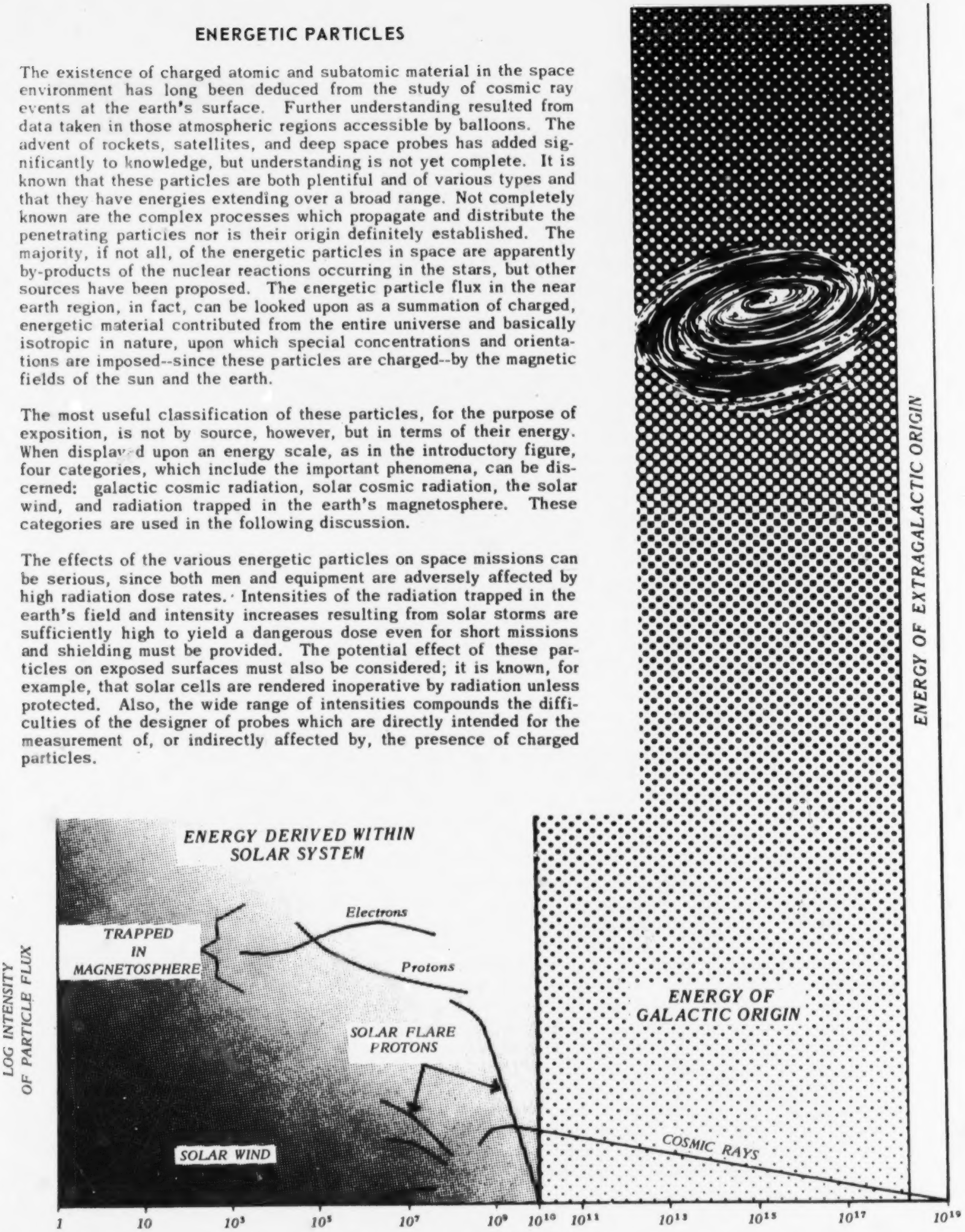
[1] *If any particles are trapped in geocentric orbits near the earth, the relative velocities may be as low as 8 km/sec. EGO will attempt to detect particles in geocentric orbits.*

ENERGETIC PARTICLES

The existence of charged atomic and subatomic material in the space environment has long been deduced from the study of cosmic ray events at the earth's surface. Further understanding resulted from data taken in those atmospheric regions accessible by balloons. The advent of rockets, satellites, and deep space probes has added significantly to knowledge, but understanding is not yet complete. It is known that these particles are both plentiful and of various types and that they have energies extending over a broad range. Not completely known are the complex processes which propagate and distribute the penetrating particles nor is their origin definitely established. The majority, if not all, of the energetic particles in space are apparently by-products of the nuclear reactions occurring in the stars, but other sources have been proposed. The energetic particle flux in the near earth region, in fact, can be looked upon as a summation of charged, energetic material contributed from the entire universe and basically isotropic in nature, upon which special concentrations and orientations are imposed--since these particles are charged--by the magnetic fields of the sun and the earth.

The most useful classification of these particles, for the purpose of exposition, is not by source, however, but in terms of their energy. When displayed upon an energy scale, as in the introductory figure, four categories, which include the important phenomena, can be discerned: galactic cosmic radiation, solar cosmic radiation, the solar wind, and radiation trapped in the earth's magnetosphere. These categories are used in the following discussion.

The effects of the various energetic particles on space missions can be serious, since both men and equipment are adversely affected by high radiation dose rates. Intensities of the radiation trapped in the earth's field and intensity increases resulting from solar storms are sufficiently high to yield a dangerous dose even for short missions and shielding must be provided. The potential effect of these particles on exposed surfaces must also be considered; it is known, for example, that solar cells are rendered inoperative by radiation unless protected. Also, the wide range of intensities compounds the difficulties of the designer of probes which are directly intended for the measurement of, or indirectly affected by, the presence of charged particles.



Galactic Cosmic Radiation

Particles with energies in excess of 10 mev are usually classed as galactic cosmic radiation. Energies of some of these particles are so high that their radius of curvature in the interplanetary magnetic field is of the same order of magnitude as the size of our galaxy, thus 'local' origin is unlikely. Most of those observed, however, presumably originate in our galaxy. The favored theory is that the cosmic radiation is a byproduct of the reactions that lead to a supernova. Theories have also been proposed which postulate both a beginning, with lower energies, in surface eruptions from the stars and then an acceleration process, depending on the magnetic fields in space, to bring the particles to their observed high energies.

Hydrogen nuclei constitute the greater percentage of the galactic cosmic radiation. In order of decreasing abundance occur the nuclei of helium; of the carbon, oxygen, nitrogen group; and of neon, etc., to atomic numbers as high as 26 (iron) and the nuclei of the boron, lithium, beryllium group. Electrons also occur as a minor constituent. Because of the widely distributed sources and the long, curved pathways of these particles, the radiation as perceived at some point in space is essentially isotropic, i.e., equal intensities are measured for any direction of observation. The galactic particle flux in the near earth region lies between 1 and 3 particles per square centimeter per second with the particle flux versus energy spectrum beginning near 10^7 ev, rising rather abruptly to a peak flux at 1 bev, and falling off with higher energy in approximate inverse proportion to the energy raised to the 2.5 power.

Although the net result of the transit of galactic cosmic rays through the magnetic fields of space is to produce evenly distributed radiation, departures from the isotropic condition are to be expected in regions dominated by strong 'local' magnetic fields. These fields affect the number of particles reaching a point as well as the isotropic distribution. The magnetic fields associated with the sun thus tend to shield the earth from cosmic radiation. tending to bend away particles which would otherwise proceed to the earth. There is a result about a 3 to 1 change in cosmic ray intensity near the earth over the solar cycle, with the intensities lower at the time of solar maximum. Flare activity on the sun can in some cases increase the magnetic field over a large region in space; when the earth is included within such a region, cosmic ray intensities fall (the phenomenon is known as the Forbush decrease) by a variable factor which can be as high as 15 percent of the norm. Variations in cosmic ray intensities as measured at the earth's surface itself include those in the near earth region with added complications due to the presence of the earth's atmosphere. At altitudes between 15 and 35 kilometers, the incoming primary cosmic particles hit and shatter atoms in the air introducing a new phenomenon: a complex distribution of less energetic secondary particles which shower down to the earth's surface. The flux of these secondary particles varies with altitude, latitude, longitude, and solar activity.

GALACTIC COSMIC RADIATION

ENERGIES

$10^7 - 10^{19}$ ev

ORIGIN

UNIVERSE

COMPOSITION

NUCLEI OF:

H	*85%*
He	*12%*
C, N, O	*1%*
Ne and greater	*~ .25%*
B, Li, Be	*~ .25%*
ELECTRONS	*~ 1–3%*

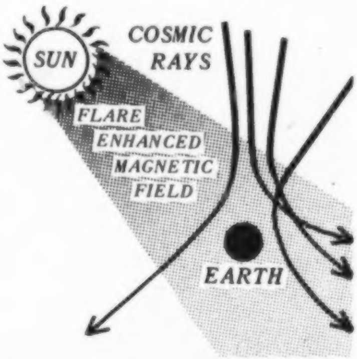
FLUX

1–3 PARTICLES/CM^2/SEC

VARIATIONS

1) *3 TO 1 CHANGE WITH SOLAR CYCLE*

2) *AS HIGH AT 10% WITH FLARE ACTIVITY*



3) *WITH PENETRATION INTO THE ATMOSPHERE*

4) *WITH LATITUDE AND LONGITUDE ON EARTH'S SURFACE*

Solar Wind and Solar Flares

Recent space experiments have shown that the solar atmosphere extends in tenuous form as an ionized gas to distances beyond the earth's orbit and that two dynamic phenomena exhibited by this atmosphere, the solar wind and solar flares, are of importance as sources of particles which reach the near earth regions. The term solar wind refers to the steady escape of ionized particles from the sun, moving in radial paths as a result of processes not completely understood but which have been conceived as a continuous expansion of the solar atmosphere. Flare phenomena are abrupt, explosive ruptures of tremendous energy in the visible solar surface which result in increased electromagnetic radiation and in increased particulate radiation, largely protons, from the sun. Solar wind particles are of low energy, but flare-ejected particles can reach the high energies typical of the galactic cosmic rays.

SOLAR PARTICLES

SOLAR WIND

CONCENTRATION:
10 PROTONS/CM^3
VELOCITY:
500 KM/SEC
ENERGY:
1.5 KEV

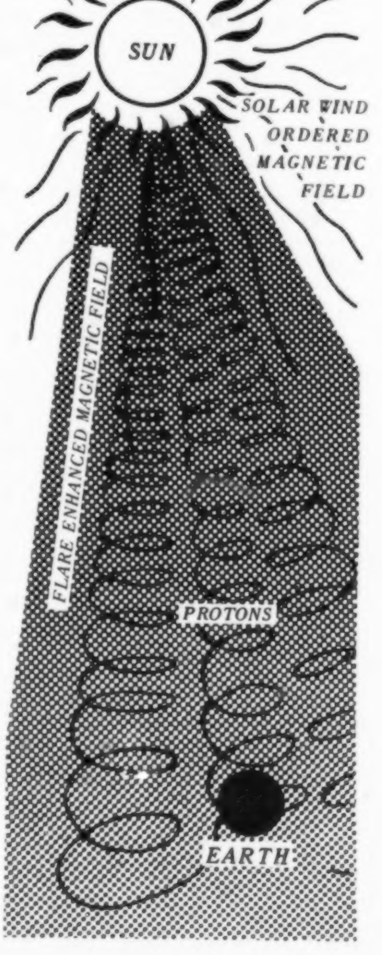
SOLAR FLARES

VELOCITY:
TO NEAR LIGHT SPEED
ENERGY:
AS HIGH AS 10 BEV

The consensus is that the solar wind is a plasma, i.e., a neutral assemblage of protons and electrons. Presumably the wind is continual. A wide variation exists in reported values for the particle concentrations in the solar wind (10^{-1} to 10^3 per cubic centimeter), and in the velocities (10^1 to 3 x 10^3 kilometers per second). Explorer 10 measurements showed plasma densities from 6–20 protons per cubic centimeter and an energy spectrum peaked at 500 ev. Mariner 2 measurements gave an energy range from 750 to 2500 ev. The figure of 10 protons per cubic centimeter with a velocity of 500 kilometers per second (1.5 kev) was recommended in a recent NASA summation as a quiet day value.

Generally speaking, the earliest solar flare proton arrivals at a point in the near earth region show directionality since they have been guided along a favorably configured magnetic field. Later arriving protons tend to come from all directions, having traveled over longer, more devious pathways or having been trapped within a magnetic field configuration which favors an isotropic arrival pattern. As these last statements imply, the magnetic field between earth and sun is not a static field. Moving plasmas carry along the magnetic fields with which they were originally associated; thus the solar wind carries along a portion of the sun's magnetism and imposes a rough radial order on the interplanetary magnetic field between sun and earth. A large portion of the complexities in solar flare proton phenomena is believed due to the fact that flares, in their early stages, increase the solar plasma emission sharply along the line of a solar radius drawn through the flare. The field between the earth and sun may, as a result of such plasma bursts, be made even more favorable for proton propagation to the near earth region; also, as pictured in the marginal drawing, the resulting field can enhance an isotropic proton arrival pattern.

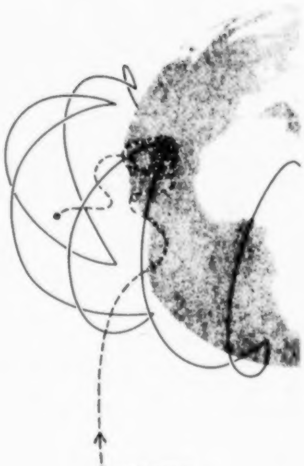
Flare phenomena are highly variable both because of the varying magnetic field conditions between sun and earth and because of variations in the processes within the sun that generate the particles. It has been said that the most typical feature of flare phenomena is their variability. Proton velocities can rise to near light speed during a relativistic flare. Energies of 1 mev to 1 bev are typical of the non-relativistic flare particles and some major flares eject particles with energies as high as 10 bev, i.e., in the galactic cosmic ray range.


SUN
SOLAR WIND ORDERED MAGNETIC FIELD
FLARE ENHANCED MAGNETIC FIELD
PROTONS
EARTH

Trapped Radiation

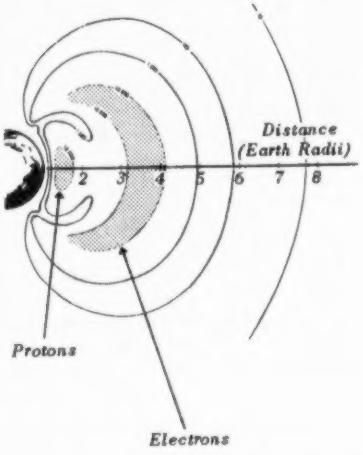
One of the earlier and more spectacular findings of the space program was the discovery that the earth is surrounded by toroidal shaped belts of energetic protons and electrons. These belts were named the Van Allen Radiation Belts after their discoverer, James Van Allen. Controversy still exists as to the ultimate source of the Van Allen particles; theories postulating the sun and/or the earth's atmosphere have been proposed as sources. The trapping mechanism is, on the other hand, well understood. Charged particles of proper energy and direction entering the earth's magnetic field are forced into pathways that spiral around magnetic lines of force. Not all particles spiral down to the surface or into the atmosphere along these paths; for many, as the earth's surface is approached, the spiral flattens until the spiraling motion is actually reversed and the particle spirals back to the other side of the earth. The spiral again flattens, the motion is repeated, and the trapped particles spiral back and forth from one hemisphere to the other. It should be added that each loop of the spiral is 'tighter' on the side nearest the earth and the cumulative effect of this is a drift in longitude superimposed on the hemisphere-to-hemisphere motion.

TRAPPED PARTICLE MOTION



The marginal figure shows counting rate contours for unshielded geiger tubes in Pioneer 3 and Explorer 4 flown through the radiation belts. The major features of the belts are easily identified. Their contours follow the lines of the earth's magnetic field with an open region over both poles. There are two regions of concentration where the counting rate peaks--the one at 1½ earth radii is caused by fast-moving protons; the maximum at 3–4 earth radii is due to energetic electrons. However, protons and electrons of lower energy are known to penetrate the whole trapping region, and the Van Allen region can be pictured as a region more or less homogeneous in character and populated by low energy electrons and protons (10^4 kev) having roughly equal flux values of 10^7 particles per square centimeter per second and energies of tens of thousands of electron volts. Superimposed on this steady background are two regions where flux values are much lower and energies considerably higher. The innermost of these regions is the proton belt, which has a flux value of ~10^2 particles per square centimeter per second in the 10–100 mev range, with the flux value dropping sharply at higher energies. The outermost of these regions consists of high energy electrons which have a peak flux between 10^3 and 10^6 particles per square centimeter per second for energies above 1 or 2 mev. Finally, a glance at the cover figure shows that while the energy of Van Allen particles is between 10^3 and 10^9 electron volts the number of particles is such that peak intensities within the belt can be significantly higher than for solar flare particles or cosmic rays.

COUNTING RATE CONTOURS



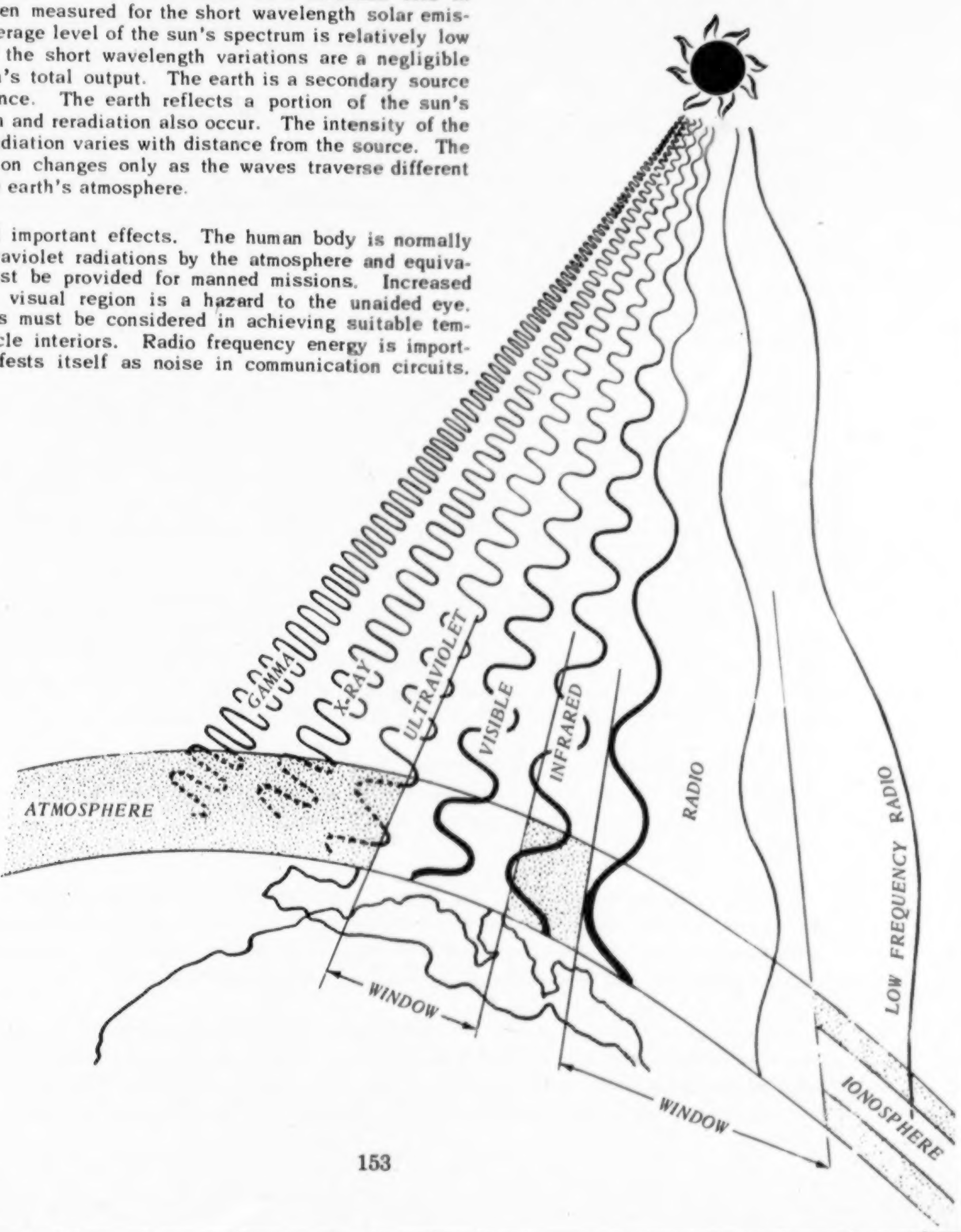
Of the two belts, the inner or proton belt is the more stable. Flux in the outer zone can vary in less than a day by a factor of ten or more, while flux in the lower zone has been observed to require a year for a change of a factor of three.

ELECTROMAGNETIC RADIATION

Electromagnetic waves with wavelengths extending across the measurable spectrum are an important factor in the interplanetary environment. Radiation occurs in the X-Ray, ultraviolet, visible and infrared regions and at radio frequencies.

The source of major importance in the near earth region is, of course, the sun. The total radiated energy (producing a flux of 0.140 watts per square centimeter at the earth's mean distance) is remarkably constant and largely concentrated in the visible region of the spectrum. Variations of as much as a thousand fold in intensity have been measured for the short wavelength solar emissions, but the average level of the sun's spectrum is relatively low in this region and the short wavelength variations are a negligible fraction of the sun's total output. The earth is a secondary source of lesser importance. The earth reflects a portion of the sun's energy; absorption and reradiation also occur. The intensity of the electromagnetic radiation varies with distance from the source. The spectral distribution changes only as the waves traverse different media, notably the earth's atmosphere.

There are several important effects. The human body is normally shielded from ultraviolet radiations by the atmosphere and equivalent shielding must be provided for manned missions. Increased luminance in the visual region is a hazard to the unaided eye. Thermal radiations must be considered in achieving suitable temperatures in vehicle interiors. Radio frequency energy is important when it manifests itself as noise in communication circuits.



Electromagnetic Radiation from the Sun

Solar radiation in the ultraviolet and X-ray regions constitutes only .2 percent of the sun's total emission. Flux levels are low and, with one or two exceptions, lie between .001 - .0001 microwatts per square centimeter in a one-angstrom band. In contrast to other regions of the solar spectrum, this region has strong emissions at particular wavelengths; the strongest (Lyman alpha) having a flux value of about .1 microwatts per square centimeter in a one-angstrom band.

The ultraviolet and X-ray emission from the sun consists of both a continuous spectrum and a line spectrum typical of highly ionized atoms. Since this radiation does not penetrate the atmosphere, the X-ray and ultraviolet region is not well known and is the concern of continuing rocket and satellite experiments.

Some inconsistencies still exist in measurements of flux values and the complete story on variation with time is not yet available. Ten-fold variation in the region below 140 angstroms has been observed to be correlated with the solar cycle, and significant variations accompany solar flare activity. Flare variations tend to take the form of enhancements of the very short wavelengths, wavelengths as short as 0.2 angstrom having been briefly observed. Current Orbiting Solar Observatory experiments are concerned with long-time study of both spectral lines and the continuous spectrum; preliminary results from OSO I indicate a 15 percent enhancement for the 304 angstrom line and a 28 percent enhancement for the 284 angstrom line during a class 2 plus solar flare.

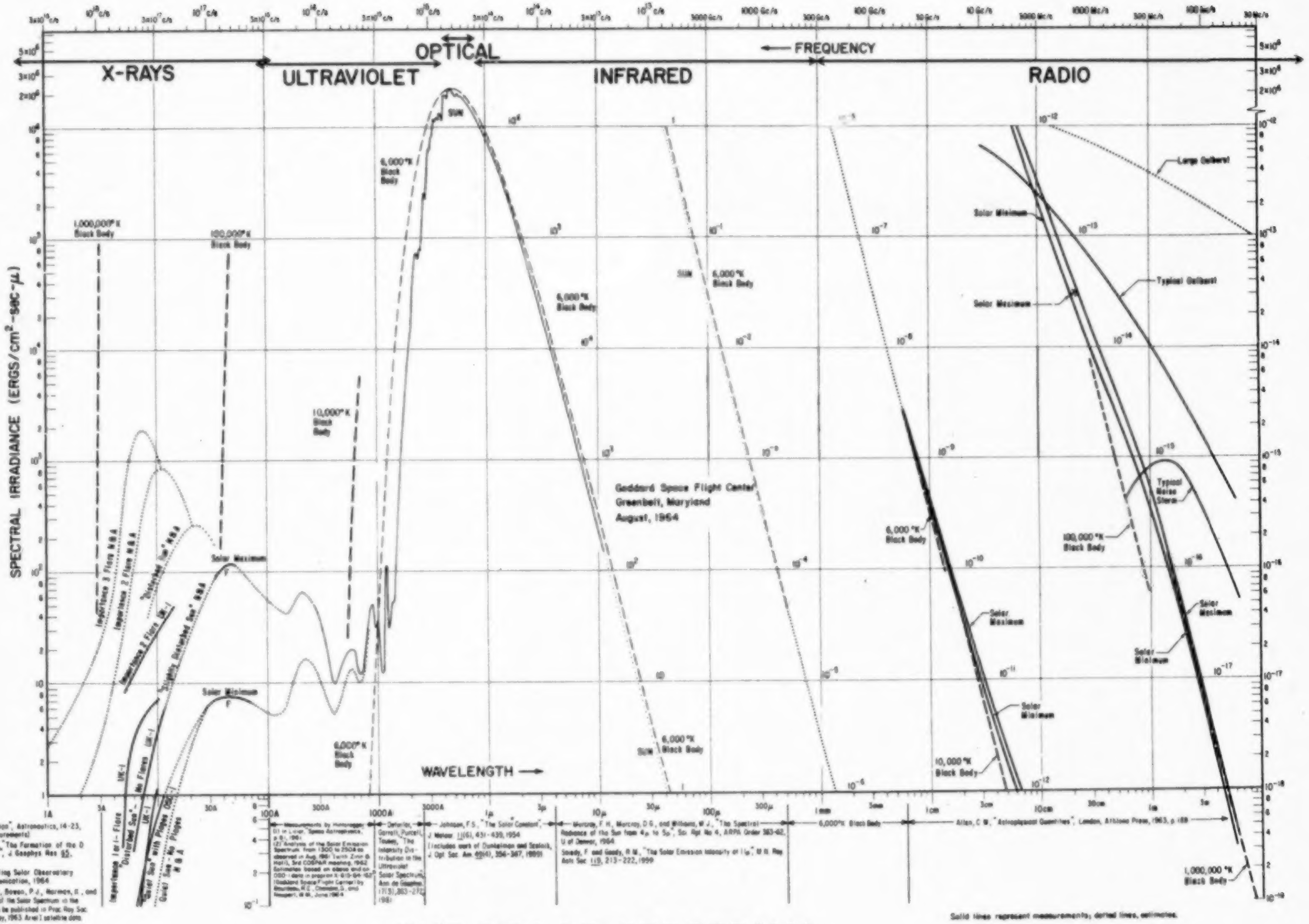
The peak in the solar emission spectrum occurs in the visible region. Radiation in the visible and infrared regions is a continuum explainable as 6000°K black body thermal radiation from the sun's photosphere. Numerous absorption lines and bands appear as a result of selective absorption by various constituents of the solar and terrestrial atmospheres. The terrestrial atmospheric constituents which give rise to the so-called telluric absorption lines and bands in the spectrum are well known and various techniques exist for predicting the solar spectrum at intermediate altitudes.

Since the visible and infrared waves carry a large percentage (99%) of the emitted solar energy, total flux values for these spectral regions are well approximated by the tabulated solar constant, which gives the total, above atmosphere flux at one astronomical unit. The visible and infrared emission of the sun is remarkably constant. The solar constant varies, predictably, with the earth-sun distance, but short term variations are smaller than 1 percent.

Solar radio waves are observed from the upper limit of the infrared waves to waves of 20 to 30 meters length. Longer waves do not penetrate to the earth's surface through the ionosphere. The steady state flux at the mean earth-sun distance is low and falls off with increasing wavelength.

Radio waves are emitted from solar regions lying above the photosphere with the shorter waves radiating from the level of the chromosphere and the longer waves from the corona, or outer solar atmosphere. The temperature of the equivalent black body is thus considerably higher than for the visible wave emission from the cooler photosphere.

The radio wave flux values are low except when certain solar flares occur. Levels can then increase by as much as a millionfold at the long wavelengths. Not all wavelengths are equally affected and the duration of the effect is variable, sometimes lasting more than a day. These transient effects are strong enough to produce severe interfering noise in communication circuits.



F = Friedman, H., "Solar Radiation", Astronautics, 14-23, August 1962 (rocket measurements)

N&A = Nicolet, M and Aikin, A.C., "The Formation of the D Region in the Ionosphere", J Geophys Res 65, 1469-1483, 1960

OSO-I = Data from the first Orbiting Solar Observatory W.A. White, private communication, 1964

UK-1 = Pounds, K.A., Willmore, A.P., Bowen, P.J., Norman, K., and Sanford, P.W., "Measurements of the Solar Spectrum in the Wavelength Band 4-14Å." To be published in Proc Roy Soc. Presented to Royal Society, May, 1963 Ariel I satellite data.

Measurements by Hinteregger: (1) in Liller, "Space Astrophysics," p. 81, 1961 (2) "Analysis of the Solar Emission Spectrum from 1300 to 250Å as observed in Aug. 1961" (with Zinn & Hall), 3rd COSPAR meeting, 1962. Estimates based on above and on OSO-I data in preprint X-615-64-162 (Goddard Space Flight Center) by Hinteregger, H.E., [illegible], and Neupert, W.M., June 1964

Detwiler, Garrett, Purcell, Tousey, "The Intensity Distribution in the Ultraviolet Solar Spectrum," Ann de Geophys. 17(3), 263-272, 1961

Johnson, F.S., "The Solar Constant", J Meteor 11(6), 431-439, 1954 (Includes work of Dunkelman and Scolnik, J Opt Soc Am 49(4), 356-367, 1959)

Murcray, F.H., Murcray, D.G., and Williams, W.J., "The Spectral Radiance of the Sun from 4μ to 5μ", Sci Rpt No 4, ARPA Order 363-62, U of Denver, 1964

Saiedy, F and Goody, R.M., "The Solar Emission Intensity at 11μ", M.N. Roy Astr Soc 119, 213-222, 1959

6,000°K Black Body

Allen, C.W., "Astrophysical Quantities", London, Athlone Press, 1963, p. 188

Solid lines represent measurements; dotted lines, estimates.

THE SOLAR SPECTRUM

Electromagnetic Radiation from the Earth

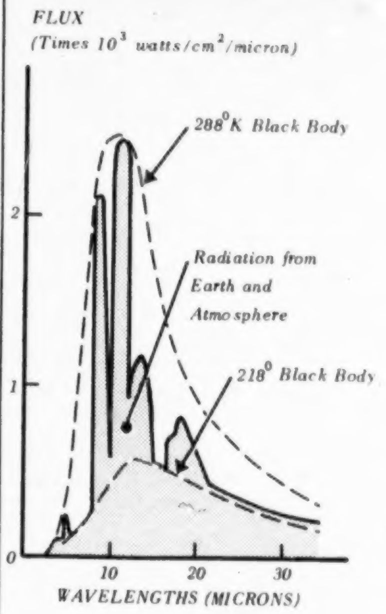
Radiant energy from the sun is in part reflected from the earth; also a fraction of the solar energy absorbed is reradiated in a continuous spectrum in the infrared. There are atmospheric absorption bands and an atmospheric window in this spectral region so that reradiation from the earth is in part from the earth's surface through the window (8 to 12 microns) and in part from the atmosphere. Reflection of solar radiation produces the greater fraction of the reversed flux in the .2 to 6 micron region.

The fraction of the solar energy reflected into space is known as the albedo, and direct measurements have been made of this quantity by the Tiros satellites. Reported reflectance values range from a low of 7 percent over the tropical Atlantic to a high of 55 percent over a dense overcast above the East Central United States.

The black body radiation from the earth in the 8 to 30 micron range has a peak near 10 microns with 288 degrees Kelvin black body radiation used as an approximation to the radiation from the surface and a 218 degrees Kelvin model for those spectral regions where the atmosphere is opaque. Tiros data show that in most cases the equivalent black body temperature for the window region corresponds closely to the temperature of the earth's surface.

The solar reflected energy input to an orbiting vehicle can be expected to be quite variable and to depend on the nature of the surface and the cloud cover underneath. Variations in albedo and equivalent black body temperatures have already been noted. Precise determinations of the total input energy, both reflected and radiated, require a knowledge of the vehicle's altitude and its orientation with respect to that portion of the earth's surface which is being illuminated by the sun.

RADIATION FROM EARTH



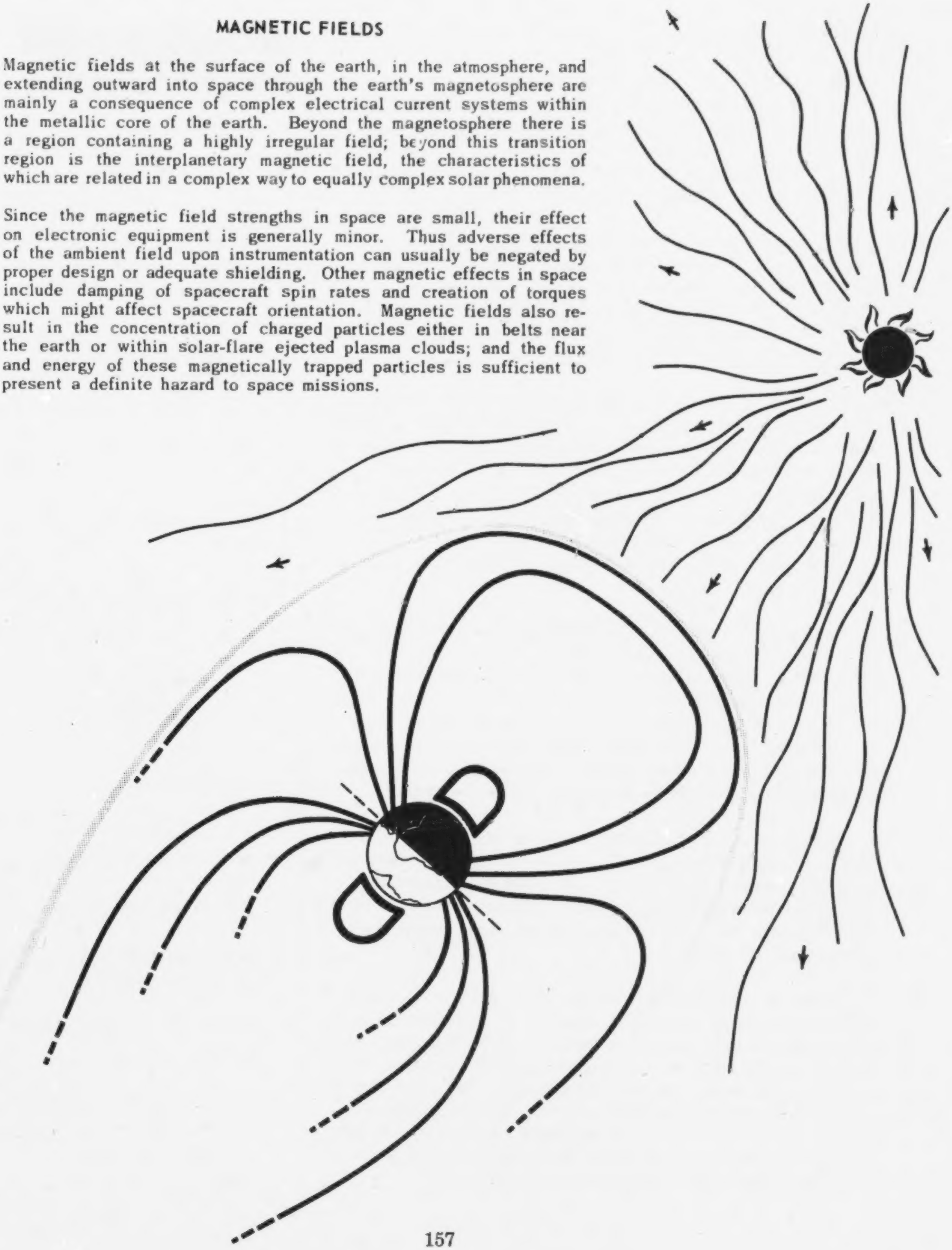
VARIATIONS

1) WITH ALBEDO (RANGE 7–55%)
2) WITH VEHICLE POSITION AND ORIENTATION

MAGNETIC FIELDS

Magnetic fields at the surface of the earth, in the atmosphere, and extending outward into space through the earth's magnetosphere are mainly a consequence of complex electrical current systems within the metallic core of the earth. Beyond the magnetosphere there is a region containing a highly irregular field; beyond this transition region is the interplanetary magnetic field, the characteristics of which are related in a complex way to equally complex solar phenomena.

Since the magnetic field strengths in space are small, their effect on electronic equipment is generally minor. Thus adverse effects of the ambient field upon instrumentation can usually be negated by proper design or adequate shielding. Other magnetic effects in space include damping of spacecraft spin rates and creation of torques which might affect spacecraft orientation. Magnetic fields also result in the concentration of charged particles either in belts near the earth or within solar-flare ejected plasma clouds; and the flux and energy of these magnetically trapped particles is sufficient to present a definite hazard to space missions.



Earth's Magnetic Field

The earth's magnetic field extends outward from the core of the earth into space. Above the ionosphere, it is called the magnetosphere. Satellite measurements indicate that the magnetosphere is not a perfect sphere but extends about 10 earth radii in the direction of the sun (Explorers 12 and 14) and least 20 earth radii directly away from the sun. (Explorer 10).

Although the magnetic field at the surface of the earth is highly irregular, it can, in general, be conceived as resulting from a magnetic dipole located near the center of the earth. The total strength of the surface field varies between approximate maxima and minima of 0.7 and 0.25 gauss. Irregularities arise from terrestrial and extraterrestrial influences.

Terrestrial influences include crustal differences in ferromagnetic content which cause local anomalies in the magnetic field at the earth's surface. Major irregularities in the surface field are believed related to the distribution and orientation of internal current and eddy systems within the molten core of the earth. These currents are continually but slowly changing in form and intensity, giving rise to secular or long-term changes in the surface field. The secular change in most areas amounts to less than two tenths of one percent per year.

Extraterrestrial phenomena are also responsible for changes in the magnetic field on the earth's surface. These variations are of short duration and have been observed to be related to solar disturbances as well as to diurnal, seasonal, and solar cycles. Duration of these deviations ranges from a fraction of a second to several days with changes in intensity ranging from .01 to several hundred gamma (1 gamma equals .00001 gauss) except in the auroral zones where considerably larger changes are not uncommon.

The two most important factors of change are the diurnal cycle, resulting in intensity changes of 50 gamma in middle latitudes and up to 200 gamma at the magnetic equator; and magnetic storms, arising from solar disturbances, which result in variations of several hundred gamma except in the auroral regions where changes up to 2,000 gamma can occur.

Values of magnetic field strengths at the surface of the earth may be used to obtain good approximations of field strengths up to an altitude of 5 earth radii since field strength in this inner region diminishes with rising altitude roughly in inverse proportion to the cube of the distance to the center of the earth. Thus, levels on the order of 0.10 gauss will be found at a mean altitude of 4000 kilometers. Above 5 earth radii the magnetosphere has a greater field strength than would be indicated by the relationship with surface intensities prevailing for altitudes below 5 earth radii.

EARTH'S MAGNETIC FIELD

EXTENT

FROM 10 EARTH RADII IN THE DIRECTION OF THE SUN TO OVER 20 RADII IN OPPOSITE DIRECTION

STRENGTH

BETWEEN .25 AND 0.7 GAUSS AT SURFACE

ANOMALIES AND VARIATIONS

1. *CAUSED BY CRUSTAL DEPOSITS*
2. *BY CHANGES IN THE EARTH'S INTERNAL CURRENT SYSTEM*
3. *SOLAR ACTIVITY AND CYCLES*
4. *DIURNAL CHANGES OF AS MUCH AS 200 GAMMA*
5. *CHANGES OF 2000 GAMMA DURING MAGNETIC STORMS*
6. *EXTRAPOLATIONS OF SURFACE FIELD ARE GOOD TO APPROXIMATELY 5 EARTH RADII*

The Interplanetary Magnetic Field

At about 10 to 15 earth radii in the direction of the sun and to greater distances in the direction away from the sun, between the magnetosphere and the interplanetary magnetic field, there appears to be a turbulent transition field. Here, extreme variations are present in both the strength and direction of the magnetic field vector as a result of interaction between the magnetosphere and the magnetic field carried along by charged particles emitted from the sun. Beyond the transition region in all directions the magnetic fields associated with the solar particles become predominant. In these fields there is a continual component from the solar particle emission (the solar wind) which extends the solar magnetic field into interplanetary regions. There is also an important but irregular component related to the increased particle emission that accompanies solar flare activity. In the absence of flare activity, the interplanetary magnetic field immediately beyond the transition field has intensities on the order of 5 to 15 gamma (Explorer 10). Variations in the interplanetary field due to flares can increase intensities by as much as five times.

Furthermore, under solar flare conditions, solar magnetic effects penetrate more deeply into the earth's magnetosphere, affect the degree of ionization in the ionosphere, and cause magnetic storms at the earth's surface.

INTERPLANETARY MAGNETIC FIELD
STRENGTH *5 – 15 GAMMA*
VARIATION *AS MUCH AS 5 TIMES DURING FLARE ACTIVITY*

GLOSSARY OF TERMS USED IN THE EXPLORATION OF SPACE

GLOSSARY OF TERMS USED IN THE EXPLORATION OF SPACE

A

Aberration—1. In astronomy, the apparent displacement of the position of a celestial body in the direction of motion of the observer, caused by the combination of the velocity of the observer and the velocity of light. 2. In optics, a deviation from perfect imagery as, for example, distortion.

Ablating Material—A material designed to dissipate heat by vaporizing or melting.

Ablating materials are used on the surfaces of some reentry vehicles. Ablating materials absorbs heat by increase in temperature and change in chemical or physical state. The heat is carried away from the surface by a loss of mass (liquid or vapor). The departing mass also blocks part of the convective heat transfer to the remaining material.

Ablation—The removal of surface material from a body by vaporization, melting, or other process; specifically the intentional removal of material from a nosecone or spacecraft during high-speed movement through a planetary atmosphere to provide thermal protection to the underlying structure. See **Ablating Material.**

Abort—To cancel or cut short a flight.

Absolute Altitude—Altitude above the actual surface of a planet or natural satellite, either land or water.

Absolute Pressure—In engineering literature, a term used to indicate pressure above the absolute zero value corresponding to empty space as distinguished from "gage pressure".

In vacuum technology, "pressure" always corresponds to absolute pressure, and therefore the term "absolute pressure" is not required.

Absolute Temperature—Temperature value relative to absolute zero.

Absolute Zero—The theoretical temperature at which all molecular motion ceases.

"Absolute zero" may be interpreted as the temperature at which the volume of a perfect gas vanishes, or more generally as the temperature of the cold source which would render a Carnot cycle 100 percent efficient. The value of absolute zero is now estimated to be –273.16° Celsius (Centigrade), –459.69° Fahrenheit, 0° Rankine.

Absorption—The process in which incident electromagnetic radiation is retained by a substance. A further process always results from absorption: that is, the irreversible conversion of the absorbed radiation into some other form of energy within and according to the nature of the absorbing medium. The absorbing medium itself may emit radiation, but only after an energy conversion has occurred.

Acceleration—The rate of change of velocity.

Decrease in velocity is sometimes called "negative acceleration."

Accelerometer—An instrument which measures acceleration or gravitational forces capable of imparting acceleration.

An accelerometer usually uses a concentrated mass (seismic mass) which resists movement because of its inertia. The displacement of the seismic mass relative to its supporting frame or container is used as a measure of acceleration.

Acceptance—The act of an authorized representative of the Government by which the Government assents to ownership by it of existing and identified articles, or approves specific services rendered as partial or complete performance of the contract.

Access Time—Of a computer, the time required under specified conditions to transfer information to or from storage, including the time required to communicate with the storage location.

Accumulator—A device or apparatus that accumulates or stores up, as: 1. A contrivance in a hydraulic system that stores fluid under pressure. 2. A device sometimes incorporated in the fuel system of a gas-turbine engine to store up and release fuel under pressure as an aid in starting.

Acoustic Excitation—Process of inducing vibration in a structure by exposure to sound waves.

Acoustic Generator—Transducer which converts electric, mechanical, or other forms of energy into sound.

Acoustic Velocity—The speed of propagation of sound waves. Also called "speed of sound."

Acquisition—1. The process of locating the orbit of a satellite or trajectory of a space probe so that tracking or telemetry data can be gathered. 2. The process of pointing an antenna or telescope so that it is properly oriented to allow gathering of tracking or telemetry data from a satellite or space probe.

Actinic—Pertaining to electromagnetic radiation capable of initiating photochemical reactions, as in photography or the fading of pigments.

Because of the particularly strong action of ultraviolet radiation on photochemical processes, the term has come to be almost synonymous with ultraviolet, as in "actinic rays".

Active—Transmitting a signal, as "active satellite," in contrast to "passive".

Adiabatic—Without gain or loss of heat.

Adsorption—The adhesion of a thin film of liquid or gas to the surface of a solid substance. The solid does not combine chemically with the adsorbed substance.

Aerobiology—The study of the distribution of living organisms freely suspended in the atmosphere.

Aeroduct—A ramjet type of engine designed to scoop up ions and electrons freely available in the outer reaches of the atmosphere or in the atmospheres of other spatial bodies, and by a chemical process within the duct of this engine, expel particles derived from the ions and electrons as a propulsive jet stream.

Aerodynamic Heating—The heating of a body produced by passage of air or other gases over the body, significant chiefly at high speeds, caused by friction and by compression processes.

Aerodynamics—The science that treats of the motion of air and other gaseous fluids, and of the forces acting on bodies when the bodies move through such fluids, or when such fluids move against or around the bodies, as "his research in aerodynamics"

Aerodynamic Vehicle—A device, such as an airplane, glider, etc., capable of flight only within a sensible atmosphere and relying on aerodynamic forces to maintain flight.

This term is used when the context calls for discrimination from "space vehicle."

Aeroelasticity—The study of the effect of aerodynamic forces on elastic bodies.

Aerolite—A meteorite composed principally of stony material.

Aeronomy—1. The study of the upper regions of the atmosphere where physical and chemical reactions due to solar radiation take place. 2. Science dealing with theories of planetary atmospheres.

Aeropause—A region of indeterminate limits in the upper atmosphere, considered as a boundary or transition region between the denser portion of the atmosphere and space.

From a functional point of view, it is considered to be that region in which the atmosphere is so tenuous as to have a negligible, or almost negligible, effect on men and aircraft, and in which the physiological requirements of man become increasingly important in the design of aircraft and auxiliary equipment.

Aerospace—(From *aero*nautics and *space*.) Of or pertaining to both the earth's atmosphere and space, as in "aerospace industries".

Aerothermodynamic Border—An altitude at about 100 miles, above which the atmosphere is so rarefied that the motion of an object through it at high speeds generates no significant surface heat.

Aerothermodynamics—The study of the aerodynamics and thermodynamic problems connected with aerodynamic heating.

Afterbody—1. A companion body that trails a satellite. 2. A section or piece of a rocket or missile that reenters the atmosphere unprotected behind the nose-cone or other body that is protected for reentry. 3. The aft part of a vehicle.

Agena—A second stage rocket which burns liquid oxygen and kerosene, often used with an ATLAS first stage by the United States for satellite and spacecraft launchings.

Agravic—Of or pertaining to a condition of no gravitation. See **Weightlessness.**

Airglow—The quasi-steady radiant emission from the upper atmosphere as distinguished from the sporadic emission of the aurorae.

Airglow is a chemiluminescence due primarily to the emission of the molecules O_2 and N_2, the radical OH, and the atoms O and Na. It may be due to released latent energy from energy stored during daylight. Emissions observed in airglow could arise from 3-body atom collisions forming molecules, from 2-body reactions between atoms and molecules, or from recombination of ions.

Historically "airglow" has referred to visual radiation. Some recent studies use "airglow" to refer to radiation outside the visual range.

Air Shower—A grouping of cosmic-ray particles observed in the atmosphere.

Primary cosmic rays slowed down in the atmosphere emit bremsstrahlung photons of high energy. Each of these photons produces secondary electrons which generate more photons and the process continues until the available energy is absorbed.

Air Sounding—The act of measuring atmospheric phenomena or determining atmospheric conditions at altitude, especially by means of apparatus carried by balloons or rockets.

Albedo—The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it, commonly expressed as a percentage. Compare Bond albedo.

The albedo is to be distinguished from the reflectivity, which refers to one specific wavelength (monochromatic radiation).

Usage varies somewhat with regard to the exact wavelength interval implied in albedo figures; sometimes just the visible portion of the spectrum is considered, sometimes the totality of wavelengths in the solar spectrum.

Alpha Particle—(Symbol ${}_2He^4$.) A positively charged particle emitted from the nuclei of certain atoms during radioactive disintegration. The alpha particle has an atomic weight of 4 and a positive charge equal in magnitude to 2 electronic charges hence it is essentially a helium nucleus (helium atom stripped of its two planetary electrons).

Alpha particles are important in atmospheric electricity as one of the agents responsible for atmospheric ionization. Minute quantities of radioactive materials such as radium, present in almost all soils and rocks, emit alpha particles and those which enter the surface air layer produce large numbers of ions along their short air paths. Alpha particles of average energy have a range of only a few centimeters in air, so radioactive matter in the earth cannot directly ionize the air above a height of a fraction of a meter. On the other hand, certain radioactive gases, such as radon and thoron, may be carried to heights of several kilometers (after initial formation during a radioactive disintegration of atoms of soil or rock matter) before emitting characteristic alpha particles which can there ionize air in the free atmosphere. The high density of ion pairs produced along the track of an alpha particle favors very rapid recombination (columnar recombination) that greatly reduces the effective ionization produced by these particles.

Ambient—Specifically, pertaining to the environment about a flying aircraft or other body but undisturbed or unaffected by it, as in "ambient air", or "ambient temperature."

Amplidyne—A special type of dc generator used as a power amplifier, in which the output voltage responds to changes in field excitation; used extensively in servo systems.

Analog Computer—A computing machine that works on the principle of measuring, as distinguished from counting, which the input data are made analogous to a measurement continuum, such as voltages, linear lengths, resistances, light intensities, etc., which can be manipulated by the computer.

Analog computers range from the relatively simple devices of the slide rule or airspeed indicator to complicated electrical machines used for solving mathematical problems.

Angel—A radar echo caused by a physical phenomenon not discernible to the eye.

Angstrom (Å)—A unit of length, used chiefly in expressing short wavelengths. Ten billion angstroms equal one meter.

Anomaly—1. In general, a deviation from the norm. 2. In geodesy, a deviation of an observed value from a theoretical value, due to an abnormality in the observed quantity. 3. In celestial mechanics, the angle between the radius vector to an orbiting body from its primary (the focus of the orbital ellipse) and the line of apsides of the orbit, measured to the direction of travel, from the point of closest approach to the primary (perifocus).

The term defined above is usually called "true anomaly", v, to distinguish it from the eccentric anomaly, E, which is measured at the center of the orbital ellipse, or from the mean anomaly, M, which is what the true anomaly would become if the orbiting body had a uniform angular motion.

Anomalistic Period—The interval between two successive perigee passes of a satellite in orbit about a primary. Also called "perigee-to-perigee period."

Anoxia—A complete lack of oxygen available for physiological use within the body. Compare hypoxia.

"Anoxia" is popularly used as a synonym for "hypoxia." This usage should be avoided.

Antigravity—A hypothetical effect that would arise from some energy field's cancellation of the effect of the gravitational field of the earth or other body.

Aphelion—That orbital point farthest from the sun when the sun is the center of attraction. That point nearest the sun is called "perihelion."

The aphelion of the earth is 1.520 x 10^{13} cm from the sun.

Apogee—In an orbit about the earth, the point at which the satellite is farthest from the earth; the highest altitude reached by a sounding rocket.

Apogee Rocket—A rocket attached to a satellite or spacecraft designed to fire when the craft is at apogee, the point farthest from the earth in orbit. The effect of the apogee rocket is to establish a new orbit farther from the earth or to allow the craft to escape from earth orbit.

Apollo—United States program with the objective of earth-orbiting a space laboratory, launching astronauts to the vicinity of the moon, and landing a man on the moon, and returning him to earth.

Arago Point—One of the three commonly detectable points along the vertical circle through the sun at which the degree of polarization of skylight goes to zero; a neutral point.

The Arago point, so named for its discoverer, is customarily located at about 20° above the antisolar point; but it lies at higher elevations in turbid air. The latter property makes the Arago distance a useful measure of atmospheric turbidity. Measurements of the location of this neutral point are typically more easily carried out than measurements of the Babinet point and the Brewster point, both of which lie so close to the sun (about 20° above and below the sun, respectively) that glare problems become serious.

Arc-Jet Engine—A type of electrical rocket engine in which the propellant gas is heated by passing through an electric arc.

Artifical Antenna—A device which has the equivalent impedance characteristics of an antenna and the necessary power-handling capabilities, but which does not radiate or intercept radiofrequency energy. Also called "dummy antenna."

Artificial Gravity—A simulated gravity established within a space vehicle, as by rotating a cabin about an axis of a spacecraft, the centrifugal force generated being similar to the force of gravity.

Assembly—An element of a component consisting of parts and/or subassemblies which performs functions necessary to the operation of the component as a whole. Examples are: pulsing networks, gyro assembly, oscillator assembly, etc.

Asteriod—One of the many small celestial bodies revolving around the sun, most of the orbits being between those of Mars and Jupiter. Also called "planetoid," "minor planet." See **Planet.**

The term "minor planet" is preferred by many astronomers but "asteriod" continues to be used in astronomical literature, especially attributively, as in "asteriod belt."

Astro—A prefix meaning "star" or "stars" and, by extension, sometimes used as the equivalent of "celestial," as in *astro*nautics.

Astroballistics—The study of the phenomena arising out of the motion of a solid through a gas at speeds high enough to cause ablation; for example, the interaction of a meteoroid with the atmosphere.

Astroballistics uses the data and methods of astronomy, aerodynamics, ballistics, and physical chemistry.

Astrobiology—The study of living organisms on celestial bodies other than the earth.

Astrodynamics—The practical .application of celestial mechanics, astroballistics, propulsion theory, and allied fields to the problem of planning and directing the trajectories of space vehicles.

Astronaut—1. A person who occupies a space vehicle. 2. Specifically one of the test pilots selected to participate in Project Mercury, the first United States program for manned space flight.

Astronautics—1. The art, skill, or activity of operating space vehicles. 2. In a broader sense, the science of space flight.

Astronomical Unit (abbr AU)—In the astronomical system of measures, a unit of length usually defined as the distance from the Earth to the Sun, approximately 92,900,000 statute miles or 14,960,000 kilometers. It is more precisely defined as the unit of distance in terms of which, in Kepler's Third Law, $n^2a^3 = k^2(1 + m)$, the semimajor axis a of an elliptical orbit must be expressed in order that the numerical value of the Gaussian constant, k, may be exactly 0.01720209895 when the unit of time is the ephemeris day.

In astronomical units, the mean distance of the Earth from the Sun, calculated by Kepler's law from the observed mean motion n and adopted mass m, is 1.00000003.

Atlas—An intercontinental ballistic missile which a total THRUST of about 360,000 pounds, frequently used as a first stage for satellite and spacecraft launchings by the United States. It is a liquid-fueled rocket, burning liquid oxygen and kerosene.

Atmosphere—The envelope of air surrounding the earth; also the body of gases surrounding or comprising any planet or other celestial body.

Atmospheric Drag—The retarding force produced on a satellite by its passage through the gas of the high atmosphere. It drops off exponentially with height, and has a small effect on satellites whose PERIGEE is higher than a few hundred kilometers.

Atomic Clock—A precision clock that depends for its operation on an electrical oscillator (as a quartz crystal) regulated by the natural vibration frequencies of an atomic system (as a beam of cesium atoms or ammonia molecules).

Attenuation—In physics, any process in which the flux density (or power, amplitude, intensity, illuminance, etc.) of a "parallel beam" of energy decreases with increasing distance from the energy source. Attenuation is always due to the action of the transmitting medium itself (mainly by absorption and scattering). It should not be applied to the divergence of flux due to distance alone, as described by the inverse-square law. See **Absorption.**

The space rate of attenuation of electromagnetic radiation is described by Bouguer's law.

In meteorological optics, the attenuation of light is customarily termed "extinction." (The latter is sometimes used with regard to any electromagnetic radiation.)

Attitude—The position or orientation of an aircraft, spacecraft, etc., either in motion or at rest, as determined by the relationship between its axes and some reference line or plane such as the horizon.

Auger Shower—A very large cosmic-ray shower. Also called "extensive air-shower."

Augmentation—The apparently larger semi-diameter of a celestial body, when seen against the horizon, as compared to its apparent decrease in size with increased altitude.

The term is used principally in reference to the moon.

Aurora—The sporadic visible emission from the upper atmosphere over middle and high latitudes. Also called "northern lights."

Aurora Australia—The aurora of the Southern Hemisphere. See **Aurora.**

Aurora Borealis—The aurora of northern latitudes. Also called "aurora polaris," "northern lights." See **Aurora.**

Axis—(pl. axes) 1. A straight line about which a body rotates, or around which a plane figure may rotate to produce a solid; a line of symmetry. 2. One of a set of reference lines for certain systems of coordinates.

Azimuth—1. Horizontal direction or bearing. Compare azimuth angle, bearing. 2. In navigation, the horizontal direction of a celestial point from a terrestrial point, expressed as the angular distance from a reference direction, usually measured from 000° at the reference direction clockwise through 360°.

Azusa—A short range tracking system which gives space position and velocity of the object being tracked.

B

Backout—An undoing of things already done during a countdown, usually in reverse order.

Backup—1. An item kept available to replace an item which fails to perform satisfactorily. 2. An item under development intended to perform the same general function performed by another item also under development.

Baker-Nunn Camera—A large camera used in tracking satellites.

Balance—1. The equilibrium attained by an aircraft, rocket, or the like when forces and moments are acting upon it so as to produce steady flight, especially without rotation about its axes; also used with reference to equilibrium about any specified axis, as, an airplane in balance about its longitudinal axis. 2. A weight that counterbalances something, especially, on an aircraft control surface, a weight installed forward of the hinge axis to counterbalance the surface aft of the hinge axis.

Ballistics—The science that deals with the motion, behavior, and effects of projectiles, especially bullets, aerial bombs, rockets, or the like; the science or art of designing and hurling projectiles so as to achieve a desired performance.

Ballistic Trajectory—The trajectory followed by a body being acted upon only by gravitational forces and the resistance of the medium through which it passes.

A rocket without lifting surfaces is in a ballistic trajectory after its engines cease operating.

Balloon-type Rocket—A rocket, such as Atlas, that requires the pressure of its propellants (or other gases) within it to give it structural integrity.

Bar—Unit of pressure equal to 10^6 dyne per cm^2 (10^6 barye) 1000 millibars, 29.53 in. of Hg.

Barye—Something used by British to denote pressure unit of the cgs system of physical units, equal to one dyne per cm^2 (0.001 millibar). See **Microbar.**

Beam—1. A ray or collection of focused rays of radiated energy. See beam width, radiation pattern. 2. = electron beam. 3. A beam (sense 1) of radio waves used as a navigation aid.

Binary Notation—A system of positional notation in which the digits are coefficients of powers of the base 2 in the same way as the digits in the conventional decimal system are coefficients of powers of the base 10.

Binary notation employs only two digits, 1 and 0, therefore is used extensively in computers where the "on" and "off" positions of a switch or storage device can represent the two digits.

In decimal notation $111 = (1 \times 10^2) + (1 \times 10^1) + (1 \times 10^0) = 100 + 10 + 1 =$ *one hundred and eleven.*

In binary notation $111 = (1 \times 2^2) + (1 \times 2^1) \times (1 \times 2^0) = 4 + 2 + 1 =$ *seven.*

Bionics—The study of systems which function after the manner of, or in a manner characteristic of, or resembling, living systems.

Bipropellant—A rocket propellant consisting of two unmixed or uncombined chemicals (fuel and oxidizer) fed to the combustion chamber separately.

Bird—A colloquial term for a rocket, satellite, or spacecraft.

Bit—(From *b*inary dig*it*.) A unit of information.

Black Body (abbr b).—1. A hypothetical "body" which absorbs all of the electromagnetic radiation striking it; that is, one which neither reflects nor transmits any of the incident radiation.

No actual substance behaves as a true black body, although platinum black and other soots rather closely approximate this ideal. However, one does speak of a black body with respect to a particular wavelength interval. This concept is fundamental to all of the radiation laws, and is to be compared with the similarly idealized concepts of the white body and the gray body. In accordance with Kirchoff's law, a black body not only absorbs all wavelengths, but emits at all wavelengths and does so with maximum possible intensity for any given temperature.

Black Box—Colloquially, any unit, usually an electronic device such as an amplifier, which can be mounted in a rocket, spacecraft, or the like as a single package. See **Component.**

Blackout—1. A fadeout of radio communications due to environmental factors such as ionospheric disturbances, or a plasma sheath surrounding a reentry vehicle. 2. A condition in which vision is temporarily obscured by a blackness, accompanied by a dullness of certain of the other senses, brought on by decreased blood pressure in the head and a consequent lack of oxygen, as may occur in pulling out of a high-speed dive in an airplane.

Blockhouse—(Also written "block house"). A reinforced concrete structure, often built underground or partly underground, and sometimes dome-shaped, to provide protection against blast, heat, or explosion during rocket launchings or related activities; specifically, such a structure at a launch site that houses electronic control instruments used in launching a rocket.

Boilerplate—As in "boilerplate caspule," a metal copy of the flight model, the structure or components of which are heavier than the flight model.

Boiloff—The vaporization of a cold propellant such as liquid oxygen or liquid hydrogen, as the temperature of the propellant mass rises as in the tank of a rocket being readied for launch.

"Bola" Concept—Concept of a manned nuclear vehicle in which a long cable separates the manned platform from the reactor power system, with consequent reduction of biological hazard and the need for heavy shielding.

Boltzmann's Constant—The ratio of the universal gas constant to Avogadro's number; equal to 1.3804×10^{-16} ergs per degree K. Sometimes called "gas constant per molecule," "Boltzmann's universal conversion factor."

Bond Albedo—The ratio of the amount of light reflected from a sphere exposed to parallel light to the amount of light incident upon it. Sometimes shortened to "albedo."

The Bond albedo is used in planetary astronomy.

Booster—Short for "booster engine" or "booster rocket."

Booster Engine—An engine, especially a booster rocket, that adds its thrust to the sustainer engine.

Booster Rocket—1. A rocket engine, either solid or liquid fuel, that assists the normal propulsive system or sustainer engine of a rocket or aeronautical vehicle in some phase of its flight. 2. A rocket used to set a missile vehicle in motion before another engine takes over.

In sense 2 the term "launch vehicle" is more commonly used.

Boostglide Vehicle—A vehicle (half aircraft, half spacecraft) designed to fly to the limits of the sensible atmosphere, then be boosted by rockets into the space above, returning to earth by gliding under aerodynamic control.

Bouguer's Law—A relationship describing the rate of decrease of a flux density of a plane-parallel beam of monochromatic radiation as it penetrates a medium which both scatters and absorbs at that wavelength.

Braking Ellipses—A series of ellipses, decreasing in size due to aerodynamic drag, followed by a spacecraft in entering a planetary atmosphere.

In theory, this maneuver will allow a spacecraft to dissipate energy through aerodynamic heating without burning up.

Breakoff Phenomenon—The feeling which sometimes occurs during high-altitude flight of being totally separated and detached from the earth and human society. Also called the "breakaway phenomenon."

Bremsstrahlung Effect—The emission of electromagnetic radiation as a consequence of the acceleration of charged elementary particles, such as electrons, under the influence of the attractive or repulsive force—fields of atomic nuclei near which the ambient, charged particle moves.

In cosmic-ray shower production, bremsstrahlung (in German, "braking radiation") effects give rise to emission of gamma rays as electrons encounter atmospheric nuclei. The emission of radiation in the bremsstrahlung effect is merely one instance of the general rule that electromagnetic radiation is emitted only when electric charges undergo acceleration.

British Thermal Unit (Btu)—The amount of heat required to raise 1 pound of water at 60°F, 1°F. General usage makes 1 Btu equal 252 calories.

Buffer—In computers: 1. An isolating circuit used to avoid reaction of a driven circuit on the corresponding driving circuit. 2. A storage device used to compensate for a difference in rate of flow of information or time on occurrence of events when transmitting information from one device to another.

Burn—A period during which a rocket engine is firing, as in "second burn" the second period during a flight in which the engine is firing.

Burning Rate (abbr r).—Velocity at which a solid propellant in a rocket is consumed, measured in a direction normal to the propellant surface and is usually expressed in inches per second.

Burnout—1. An act or instance of the end of fuel and oxidizer burning in a rocket; the time at which this burnout occurs. Compare cutoff. 2. An act or instance of something burning out or of overheating; specifically, an act or instance of a rocket combustion chamber, nozzle, or other part overheating so as to result in damage or destruction.

Burst—1. A single pulse of radio energy; specifically such a pulse at radar frequencies. 2. Solar radio burst. 3. Cosmic ray burst.

C

Calorie—Originally amount of heat required to raise temperature of one gram of water through one degree centigrade (the gram-calorie), but a more precise expression is that a 15° gram-calorie (cal $_{15}$) is the amount of heat required to raise the temperature of one gram of water from 14.5°C to 15.5°C and is equal to 4.1855 joules.

Capacity—In computer operations: 1. The largest quantity which can be stored, processed, or transferred. 2. The largest number of digits or characters which may be regularly processed. 3. The upper and lower limits of the quantities which may be processed.

Capsule—1. A boxlike component or unit, often sealed. 2. A small, sealed, pressurized cabin with an internal environment which will support life in a man or animal during extremely high altitude flight, space flight, or emergency escape.

The term, "spacecraft," is preferred to capsule for any man-carrying vehicle.

Cascade Shower—A group occurrence of cosmic rays. Also called "air shower."

Cavitation—The turbulent formation of bubbles in a fluid, occurring whenever the static pressure at any point in the fluid flow becomes less than the fluid vapor pressure.

Celestial Mechanics—The study of the theory of the motions of celestial bodies under the influence of gravitational fields.

Celestial Sphere—An imaginary sphere of infinite radius concentric with the earth, on which all celestial bodies except the earth are assumed to be projected.

Centrifuge—A mechanical device which applies centifugal force to the test specimen by means of a long rotating arm to simulate very closely the prolonged accelerations encountered in high-performance aircraft, rockets, and spacecraft.

The simulated acceleration of centrifugal force produced is proportional to the distance from the center of rotation and the square of the rotational velocity.

Characteristic—Any dimensional, visual, functional, mechanical, electrical, chemical, physical, or material feature or property; and any process-control element which describes and establishes the design, fabrication, and operating requirements of an article.

Chase Pilot—A pilot who flies in an escort apirlane advising a pilot who is making a check, training, or research flight in another craft.

Checkout—1. A sequence of actions taken to test or examine a thing as to its readiness for incorporation into a new phase of use, or for the performance of its intended function. 2. The sequence of steps taken to familiarize a person with the operation of an airplane or other piece of equipment.

In sense 1, a checkout is usually taken at a transition point between one phase of action and another. To shorten the time of checkout, automation is frequently employed.

Cheese Antenna—A cylindrical parabolic reflector enclosed by two plates perpendicular to the cylinder, so spaced as to permit the propagation of more than one mode in the desired direction of polarization. It is fed on the focal line.

Chemical Fuel—1. A fuel that depends upon an oxidizer for combustion or for development of thrust, such as liquid or solid rocket fuel or internal-combustion-engine fuel; distinguished from nuclear fuel. 2. A fuel that uses special chemicals, such as a boron-based fuel.

Chemical Rocket—A rocket using chemical fuel, fuel which requires an oxidizer for combustion, such as liquid or solid rocket fuel.

Chemosphere—The vaguely defined region of the upper atmosphere in which photochemical reactions take place. It is generally considered to include the stratosphere (or the top thereof) and the mesosphere, and sometimes the lower part of the thermosphere.

This entire region is the seat of a number of important photochemical reactions involving atomic oxygen 0, molecular oxygen O_2, ozone O_3, hydroxyl OH, nitrogen N_2, sodium Na, and other constituents to a lesser degree.

Chromosphere—A thin layer of relatively transparent gases above the PHOTOSPHERE of the sun. It is most easily observed during a total solar eclipse.

Chokes—Pain and irritation in the chest and throat as a result of reduced ambient pressure.

Chugging—A form of combustion instability, especially in a liquid-propellant rocket engine, characterized by a pulsing operation at a fairly low frequency, sometimes defined as occurring between particular frequency limits; the noise made in this kind of combustion. Also called "chuffing."

Cislunar—(Latin cis "on this side".) Of or pertaining to phenomena, projects, or activity in the space between the earth and moon, or between the earth and the moon's orbit.

Closed Ecological System—A system that provides for the maintenance of life in an isolated living chamber such as a spacecraft cabin by means of a cycle wherein exhaled carbon dioxide, urine, and other waste matter are converted chemically or by photosynthesis into oxygen, water, and food.

Coherent—Of electromagnetic radiation, being in phase so that waves at various points in space act in unison.

Cold-flow Test—A test of a liquid rocket without firing it to check or verify the efficiency of a propulsion subsystem, providing for the conditioning and flow of propellants (including tank pressurization, propellant loading, and propellant feeding.)

Comet—A luminous member of the solar system composed of a head or coma at the center of which a presumably solid nucleus is sometimes situated, and often with a spectacular gaseous tail extending a great distance from the head.

Command—A signal which initiates or triggers an action in the device which receives the signal.

The orbits of comets are highly elliptical.

Communications Satellite—A satellite designed to reflect or relay radio or other communications waves.

Companion Body—A nose cone, last-stage rocket, or other body that orbits along with an earth satellite.

Complex—Entire area of launch site facilities. This includes blockhouse, launch pad, gantry, etc. Also referred to as a "launch complex."

Component—A self-contained combination of parts and/or assemblies within a subsystem performing a function necessary to the subsystem's operation. Examples are: receivers, transmitters, modulators, etc.

Composite Materials—Structural materials of metal alloys or plastics with built-in strengthening agents which may be in the form of filaments, foils, or flakes of a strong material.

Composite Propellant—A solid rocket propellant consisting of a fuel and an oxidizer.

Computer—A machine for carrying out calculations and performing specified transformations on information.

Configuration—A particular type of a specified aircraft, rocket, etc., which differs from others of the same model by virtue of the arrangement of its components or by the addition or omission of auxiliary equipment as "long-range configuration," "cargo configuration."

Conic—A conic section.

Conic Section—A curve formed by the intersection of a plane and a right circular cone. Usually called "conic."

The conic sections are the ellipse, the parabola, and the hyperbola; curves that are used to describe the paths of bodies moving in space.

The circle is a special case of the ellipse, an ellipse with an eccentricity of zero.

Console—An array of controls and indicators for the monitoring and control of a particular sequence of actions, as in the checkout of a rocket, a countdown action, or a launch procedure.

A console is usually designed around desklike arrays. It permits the operator to monitor and control different activating instruments, data recording instruments, or event sequencers.

Constellation—Originally a conspicuous configuration of stars; now a region of the celestial sphere marked by arbitrary boundary lines.

Contractor—The individual(s) or concern(s) who enter(s) into a prime contract with the Government.

Contravane—A vane that reverses or neutralizes a rotation of a flow. Also called a "countervane."

Control—Specifically, to direct the movements of an aircraft, rocket, or spacecraft with particular reference to changes in altitude and speed. Contrast guidance.

Control Rocket—A vernier engine, retrorocket, or other such rocket, used to guide or make small changes in the velocity of a rocket, spacecraft, or the like.

Coriolis Acceleration—An acceleration of a particle moving in a (moving) relative coordinate system. The total acceleration of the particle, as measured in an internal coordinate system, may be expressed as the sum of the acceleration within the relative system, the acceleration of the relative system itself, and the coriolis acceleration.

In the case of the earth, moving with angular velocity Ω, a particle moving relative to the earth with velocity V has the coriolis acceleration $2\Omega \times V$. If Newton's laws are to be applied in the relative system, the coriolis acceleration and the acceleration of the relative system must be treated as forces. See **Gravity.**

Corona—1. The faintly luminous outer envelope of the sun. Also called "solar corona."

The corona can be observed at the earth's surface only at solar eclipse or with the coronagraph, a photographic instrument which artificially blocks out the image of the body of the sun.

2. Discharge of electricity which occurs at the surface of a conductor under high voltage. The phenomenon is dependent or ambient pressure of the gas surrounding the conductor.

Since phenomenon is enhanced by reduced pressure, tests must be conducted to verify that no significant corona exists within the spacecraft or its components under anticipated conditions.

Cosmic Dust—Small meteoroids of a size similar to dust.

Cosmic Rays—The aggregate of extremely high energy subatomic particles which bombard the atmosphere from outer space. Cosmic-ray primaries seem to be mostly protons, hydrogen nuclei, but also comprise heavier nuclei. On colliding with atmospheric particles they produce many different kinds of lower-energy secondary cosmic radiation (see **Cascade Shower.**) Also called "cosmic radiation."

The maximum flux of cosmic rays, both primary and secondary, is at an altitude of 20 km, and below this the absorption of the atmosphere reduces the flux, though the rays are still readily detectable at sea level. Intensity of cosmic ray showers has also been observed to vary with latitude, being more intense at the poles.

COSPAR—Abbreviation for "Committee on Space Research," International Council of Scientific Unions.

Countdown—The time period in which a sequence of events is carried out to launch a rocket; the sequence of events.

Cryogenic Propellant—A rocket fuel, oxidizer, or propulsion fluid which is liquid only at very low temperatures.

Cryogenic Temperature—In general, a temperature range below about —50°C; more particularly, temperatures within a few degrees of absolute zero.

Cutoff—An act or instance of shutting something off; specifically in rocketry, an act of instance of shutting off the propellant flow in a rocket, or of stopping the combustion of the propellant.

D

Data Reduction—Transformation of observed values into useful, ordered, or simplified information.

Debug—1. To isolate and remove malfunctions from a device, or mistakes from a computer routine or program. 2. Specifically, in electronic manufacturing, to operate equipment under specified environmental and test conditions in order to eliminate early failures and to stabilize equipment prior to actual use.

Deceleration—1. The act or process of moving, or of causing to move, with decreasing speed; the state of so moving. 2. A force causing deceleration; also, inertial forces sometimes called "negative acceleration".

Deep Space Net—A combination of three radar and communications stations in the United States, Australia, and South Africa so located as to keep a spacecraft in deep space under observation at all times.

Deep Space Probes—Spacecraft designed for exploring space to the vicinity of the moon and beyond. Deep space probes with specific missions may be referred to as "lunar probe," "Mars probe," "solar probe," etc.

Degradation—Gradual deterioration in performance.

Delay—The time (or equivalent distance) displacement of some characteristic of a wave relative to the same characteristics of a reference wave; that is, the difference in phase between the two waves. Compare lag.

In one-way radio propagation, for instance, the phase delay of the reflected wave over the direct wave is a measure of the extra distance traveled by the reflected wave in reaching the same receiver.

Design Engineering Tests—Environmental tests having the purpose of trying certain design features prior to finalizing design for Design Qualification Tests. For instance the structural model of the spacecraft is subjected to certain environmental exposures or Design Engineering Tests up to design qualification level in order to establish confidence in its structural design.

Design Qualification Tests—Series of environmental and other tests applied to prototype spacecraft, subsystems, components, or experiments to determine if design meets requirements for launch and flight of spacecraft. These tests are planned to subject spacecraft to considerably greater rigors of environment than expected during launch and flight in order to achieve maximum design reliability.

Destruct—The deliberate action of destroying a rocket vehicle after it has been launched, but before it has completed its course.

Destructs are executed when the rocket gets off its plotted course or functions in a way so as to become a hazard.

Deviation—1. In NASA quality control, specific authorization, granted before the fact, to depart from a particular requirement of specifications or related documents. 2. In statistics, the difference between two numbers. Also called "departure." It is commonly applied to the difference of a variable from its mean, or to the difference of an observed value from a theoretical value.

Digital Computer—A computer which operates on the principle of counting as opposed to measuring. See **Analog Computer.**

Diplexer—A device permitting an antenna system to be used simultaneously or separately by two transmitters. Compare with duplexer.

Dish—A parabolic type of radio or radar antenna, roughly the shape of a soup bowl.

Display—The graphic presentation of the output data of a device or system as, for example, a radar scope.

Docking—The process of bringing two spacecraft together while in space.

Doppler Shift—The change in frequency with which energy reaches a receiver when the source of radiation or a reflector of the radiation and the receiver are in motion relative to each other. The Doppler shift is used in many tracking and navigation systems.

Dosimeter—A device, worn by persons working around radioactive material, which indicates the amount (dose) of radiation to which they have been exposed.

Dovap—From Doppler, velocity and position, a tracking system which uses the Doppler shift caused by a target moving relative to a ground transmitter to obtain velocity and position information.

Drogue Parachute—A type of parachute attached to a body, used to slow it down; also called "deceleration parachute," or "drag parachute."

Duplexer—A device which permits a single antenna system to be used for both transmitting and receiving.

"Duplexer" should not be confused with "diplexer,"

a device permitting an antenna system to be used simultaneously or separately by two transmitters.

Dynamic Pressure—Symbol q. 1. The pressure exerted by a fluid, such as air, by virtue of its motion, equal to one half the fluid density times the fluid velocity square $\frac{1}{2}\rho V^2$.

2. The pressure exerted on a body, by virtue of its motion through a fluid, for example, the pressure exerted on a rocket moving through the atmosphere.

Dyne (abbr d)—That unbalanced force which acting for 1 second on body of 1 gram mass produces a velocity change of 1 cm/sec.

The dyne is the unit of force in the cgs system.

Dysbarism—A general term which includes a complex group of a wide variety of symptoms within the body caused by changes in ambient pressure, exclusive of hypoxia.

E

Ebullism—The formation of bubbles, with particular reference to water vapor bubbles in biological fluids, caused by reduced ambient pressure.

Eccentric—Not having the same center; varying from a circle, as in "eccentric orbit."

Echo—A large plastic balloon with a diameter of 30 meters and weight of 50 kilograms launched on August 12, 1960 by the United States and inflated in orbit. It was launched as a passive communications satellite, to reflect microwaves from a transmitter to a receiver beyond the horizon.

Ecliptic—The apparent annual path of the sun among the stars; the intersection of the plane of the earth's orbit with the celestial sphere.

This is a great circle of the celestial sphere inclined at an angle of about 23°27' to the celestial equator.

Ecological System—A habitable environment, either created articially, such as in a manned space vehicle, or occurring naturally, such as the enviroment on the surface of the earth, in which man, animals, or other organisms can live in mutual relationship with each other.

Ideally, the environment furnishes the sustenance for life, and the resulting waste products revert or cycle back into the environment to be used again for the continuous support of life.

Effective Atmosphere—1. That part of the atmosphere which effectively influences a particular process or motion, its outer limits varying according to the terms of the process or motion considered.

For example, an earth satellite orbiting at 250 miles altitude remains within the ionosphere, but because the air particles are so rare at this altitude as to cause no appreciable friction or deflection, the satellite may be considered to be outside the effective atmosphere. For movement of air vehicles the effective atmosphere ends at the aerospause (which see.)

Ejection Capsule—1. In an aircraft or manned spacecraft, a detachable compartment serving as a cockpit or cabin, which may be ejected as a unit and parachuted to the ground. 2. In an artificial satellite, probe, or unmanned spacecraft, a boxlike unit usually containing recording instruments or records of observed data, which may be ejected and returned to earth by a parachute or other deceleration device.

Elasticizer—An elastic substance or fuel used in a solid rocket propellant to prevent cracking of the propellant grain and to bind it to the combustion-chamber case.

Electric Propulsion—The generation of thrust for a rocket engine involving acceleration of a propellant by some electrical device such as an arc jet, ion engine, or magnetohydrodynamic accelerator.

Electromagnetic Radiation—Energy propagated through space or through material media in the form of an advancing disturbance in electrical and magnetic fields existing in space or in the media. Also called simply "radiation."

Electron—The subatomic particle that possesses the smallest possible electric charge.

The term "electron" is usually reversed for the orbital particle whereas the term "beta particle" refers to a particle of the same electric charge inside the nucleus of the atom.

Electron Volt—A unit of energy equal to 1.601 × 10^{-12} erg. It is defined as the kinetic energy gained by an electron which is accelerated through a potential difference of one volt.

Electronic Data Processing—The use of electronic devices and systems in the processing of data so as to interpret the data and put it into usable form.

Ellipse—A plane curve constituting the locus of all points the sum of whose distances from two fixed point called "foci" is constant; an elongated circle.

The orbits of planets, satellites, planetoids, and comets are ellipses; center of attraction is at one focus.

Emissivity—1. The ratio of the emittance of a given surface at a specified wavelength and emitting temperature to the emittance of an ideal black body at the same wavelength and temperature. Sometimes called "emissive power."

The greatest value that an emissivity may have is unity, the least value zero. It is a corollary of Kirchhoff's law that the emissivity of any surface at a specified temperature and wavelength is exactly equal to the absorptivity of that surface at the same temperature and wavelength. The spectral emissivity is for a definite wavelength. The total emissivity is for all wavelengths.

2. (abbr ϵ) Specifically, the ratio of the flux emitted by a clean, perfectly polished surface of the material to the flux that would have been emitted by a black body at the same temperature.

Environment—An external condition or the sum of such conditions, in which a piece of equipment or a system operates, as in "temperature environment," "vibration environment," or "space environment."

Environments are usually specified by a range of values, and may be either natural or artificial.

Epoch—A particular instant for which certain data are valid.

Escape Velocity—The radial speed which a particle or larger body must attain in order to escape from the gravitational field of a planet or star.

The escape velocity from Earth is approximately 7 miles per sec.; from Mars, 3.2 miles per sec.; and from the Sun, 390 miles per sec. In order for a celestial body to retain an atmosphere for astronomically long periods of time, the mean velocity of the atmospheric molecules must be considerably below the escape velocity.

Exhaust Velocity—The speed at which the exhaust gases are expelled from the nozzle of a rocket. It depends upon the propellant-burning characteristics, and the over-all engine efficiency. Present exhaust velocities using liquid oxygen and kerosene are of the order of 8000 feet per second, about half the theoretical maximum for chemical propellants.

Exobiology—The study of living organisms existing on celestial bodies other than the earth.

Exosphere—The outermost, or topmost portion of the atmosphere.

In the exosphere, the air density is so low that the mean free path of individual particles depends upon their direction with respect to the local vertical, being greatest for upward moving particles. It is only from the exosphere that atmospheric gases can, to any appreciable extent, escape into outer space.

Exotic Fuel—Any fuel considered to be unusual, as a boron-based fuel.

Experiment—A combination of two or more components, including both the sensor and associated electronics, designed for acquisition of data for space research.

Explosive Bolt—A bolt incorporating an explosive which can be detonated on command, thus destroying the bolt. Explosive bolts are used, for example, in separating a satellite from a rocket.

Extraterrestrial—From outside the earth.

Extraterrestrial Radiation—In general, solar radiation received outside the earth's atmosphere.

Eyeballs In, Eyeballs Out—Terminology used by test pilots to describe the acceleration experienced by the person being accelerated. Thus the acceleration experienced by an astronaut at lift-off is "eyeballs in" (positive g in terms of vehicle acceleration), and the acceleration experienced when retrorockets fire is "eyeballs out" (negative **g** in terms of vehicle acceleration.)

F

Fallaway Section—A section of a rocket vehicle that is cast off and separates from the vehicle during flight, especially such a section that falls back to the earth.

Fatigue—A weakening or deterioration of metal or other material, or of a member, occurring under load, especially under repeated, cyclic, or continued loading.

Field—A region of space at each point of which a given physical quantity has some definite value, thus a "gravitational field," an "electric field," a "magnetic field," etc.

Film Cooling—The cooling of a body or surface, such as the inner surface of a rocket combustion chamber, by maintaining a thin fluid layer over the affected area.

Fixed Satellite—An earth satellite that orbits from west to east at such a speed as to remain constantly over a given place on the earth's equator.

Flare—A bright eruption from the sun's chromosphere.

Flares may appear within minutes and fade within an hour. They cover a wide range of intensity and size, and they tend to occur between sunspots.

Flares are related to radio fadeouts and terrestrial magnetic disturbances.

Flashback—A reversal of flame propagation in a system, counter to the usual flow of the combustible mixture.

Flight—Describes or pertains to travel of spacecraft or stages after liftoff. Thus, in testing, designates spacecraft or element thereof which is to be launched as distinct from structural model and prototype spacecraft which are test specimens only.

Flight Acceptance Tests—The environmental and other tests which spacecraft, subsystems, components, or experiments scheduled for flight must pass before launch. These tests are planned to approximate expected environmental conditions and have the purpose of detecting flaws in material and workmanship.

Flight Unit—Spacecraft which is undergoing or has passed Flight Acceptance Tests (environmental and other tests) which qualify it for launch and space flight.

Flux—The rate of flow of some quantity, often used in reference to the flow of some form of energy. Also called "transport." 2. In nuclear physics generally, the number of radioactive particles per unit volume times their mean velocity.

Flux Density—The flux (rate of flow) of any quantity, usually a form of energy, through a unit area of specified surface. (Note that this is not a volumetric density like radiant density.) Compare luminous density.

The flux density of electromagnetic radiation in general often is preferably specified as "radiant flux density" or "irradiance" in order to distinguish it from the slightest different concept of luminous flux density or illuminance. In radar, flux density commonly is referred to as power density. It is essential to understand that the flux density of radiation is in no sense a vector quantity, because it is the sum of the flux corresponding to all ray directions incident upon one "side" of the unit area.

Forbush Decrease—The observed decrease in COSMIC RAY activity about a day after a SOLAR FLARE. It is now believed to be caused by a shielding effect produced by magnetic fields contained in the PLASMA cloud emitted from the sun at the time of a flare.

Flying Test Bed—An aircraft, rocket, or other flying vehicle used to carry objects or devices being flight tested.

Free Fall—1. The fall or drop of a body, such as a rocket not guided, nor under thrust, and not retarded by a parachute or other braking device. 2. Weightlessness.

G

g or G—An acceleration equal to the acceleration of gravity, approximately 32.2 feet per second per second at sea level; used as a unit of stress measurement for bodies undergoing acceleration.

GSE—See Ground Support Equipment.

Gamma Ray—A quantum of electromagnetic radiation emitted by a nucleus, each such photon being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 kev and 10 Mev, with correspondingly short wavelengths and high frequencies. Also called "gamma radiation."

Gantry—A frame structure that spans over something, as an elevated platform that runs astride a work area, supported by wheels on each side; specifically, short for "gantry crane" or "gantry scaffold."

Gantry Scaffold—A massive scaffolding structure mounted on a bridge or platform supported by a pair of towers or trestles that normally run back and forth on parallel tracks, used to assemble and service a large rocket on its launching pad. Often shortened to "gantry." Also called "service tower."

This structure is a latticed arrangement of girders, tubing, platforms, cranes, elevators, instruments, wiring, floodlights, cables, and ladders—all used to attend the rocket.

Garbage—Miscellaneous objects in orbit, usually material ejected or broken away from a launch vehicle or satellite.

Gas Cap—The gas immediately in front of a meteoroid or reentry body as it travels through the atmosphere; the leading portion of a meteor. This gas is compressed and adiabatically heated to incandescence.

Generation—In any technical or technological development, as of a missile, jet engine, or the like, a stage or period that is marked by features or performances not marked, or existent, in a previous period of development or production, as in "second generation rocket."

Geo—A prefix meaning "earth," as in "geology," "geophysics."

Most writers used the established terms such as "geology" to refer to the same concept on other bodies of the solar system, as "the geology of Mars," rather than "areology" or "marsology," "geology of the moon," rather than "selenology."

Geocentric—Relative to the earth as a center; measured from the center of the earth.

Geodetic—Pertaining to geodesy, the science which deals with the size and shape of the earth.

Geoid—The equipotential surface which most nearly approximates the mean sea level of the earth.

Geomagnetism—The magnetic phenomena, collectively considered, exhibited by the earth and its atmosphere; by extension, the magnetic phenomena in interplanetary space.

Geophysics—The physics of the earth and its environment, i.e., earth, air, and (by extension), space.

Classically, geophysics is concerned with the nature of physical occurrences at and below the surface of the earth including, therefore, geology, oceanography, geodesy, seismology, hydrology, etc. The trend is to extend the scope of geophysics to include meteorology, geomagnetism, astrophysics, and other sciences concerned with the physical nature of the universe.

Geopotential—The potential energy of a unit mass relative to sea level, numerically equal to the work that would be done in lifting the unit mass from sea level to the height at which the mass is located; commonly expressed in terms of dynamic height or geopotential height.

Geoprobe—A rocket vehicle designed to explore space near the earth at a distance of more than 4,000 miles from the earth's surface. Rocket vehicles operating lower than 4,000 miles are termed "sounding rockets."

Giga—A prefix meaning multiplied by one billion.

Gimbal—1. A device with two mutually perpendicular and intersecting axes of rotation, thus giving free angular movement in two directions, on which an engine or other object may be mounted. 2. In a gyro, a support which provides the spin axis with a degree-of-freedom.

Gnotobiotics—The study of germ-free animals.

Gox—Gaseous oxygen.

Grain—An elongated molding or extrusion of solid propellant for a rocket, regardless of size.

Gravitation—The acceleration produced by the mutual attraction of two masses, directed along the line joining their centers of mass, and of magnitude inversely proportional to the square of the distance between the two centers of mass.

Gravity—The force imparted by the earth to a mass on, or close to the earth. Since the earth is rotating, the force observed as gravity is the resultant of the force of gravitation and the centrifugal force arising from this rotation.

Ground Support Equipment (GSE)—Any ground-based equipment used for launch, checkout, or in-flight support of a space project.

g-suit or G-Suit—A suit that exerts pressure on the abdomen and lower parts of the body to prevent or retard the collection of blood below the chest under positive acceleration.

G-Tolerance—A tolerance in a person or other animal, or in a piece of equipment, to an acceleration of a particular value.

Guidance—The process of directing the movements of an aeronautical vehicle or space vehicle, with particular reference to the selection of a flight path. See **Control.**

In preset guidance a predetermined path is set into the guidance mechanism and not altered, in inertial guidance accelerations are measured and integrated within the craft, in command guidance the craft responds to information received from an outside source. Beam-rider guidance utilizes a beam, terrestrial-reference guidance some influence of the earth, celestial guidance the celestial bodies and particularly the stars, and homing guidance information from the destination. In active homing guidance the information is in response to transmissions from the craft, in semiactive homing guidance the transmissions are from a source other than the craft, and in passive homing guidance natural radiations from the destination are utilized. Midcourse guidance extends from the end of the launching phase to an arbitrary point enroute and terminal guidance extends from this point to the destination.

Gyro—A device which utilizes the angular momentum of a spinning rotor to sense angular motion of its base about one or two axes at right angles to the spin axis. Also called "gyroscope."

H

Hall Effect—The electrical polarization of a horizontal conducting sheet of limited extent, when that sheet moves laterally through a magnetic field having a component vertical to the sheet.

The Hall effect is important in determining the behavior of the electrical currents generated by winds in the lower ionosphere, since these winds advect the ionized layers across the earth's magnetic field and produce a complex electrical current system in the ionosphere. This current system in turn produces small changes in the earth's magnetic field as measured at the surface.

Hardness—Of X-rays and other radiation of high energy, a measure of penetrating power. Radiation which will penetrate a 10-centimeter thickness of lead is considered "hard radiation."

Heat Exchanger—A device for transferring heat from one fluid to another without intermixing the fluids. A regenerator is an example.

Heat Shield—Any device that protects something from heat.

Heat Sink—1. In thermodynamic theory, a means by which heat is stored, or is dissipated or transferred from the system under consideration 2. A place toward which the heat moves in a system. 3. A material capable of absorbing heat; a device utilizing such a material and used as a thermal protection device on a spacecraft or reentry vehicle. 4. In nuclear propulsion, any thermodynamic device, such as a radiator or condenser, that is designed to absorb the excess heat energy of the working fluid. Also called "heat dump."

Heterosphere—The upper portion of a two-part division of the atmosphere according to the general homogeneity of atmospheric composition; the layer above the homosphere. The heterosphere is characterized by variation in composition, and mean molecular weight of constituent gases.

This region starts at 80 to 100 km above the earth, and therefore closely coincides with the ionosphere and the thermosphere.

Hold—During a countdown: To halt the sequence of events until an impediment has been removed so that the countdown can be resumed, as in "T minus 40 and holding."

Homosphere—The lower portion of a two-part division of the atmosphere according to general homogeneity of atmospheric composition; opposed to the heterosphere. The region in which there is no gross change in atmospheric composition, that is, all of the atmosphere from the earth's surface to about 80 or 100 km.

The homosphere is about equivalent to the neutrosphere, and includes the troposphere, stratosphere, and mesosphere, and also the ozonosphere and at least part of the chemosphere.

Hot Test—A propulsion system test conducted by actually firing the propellants.

Human Engineering—The art or science of designing, building, or equipping mechanical devices or artificial environments to the anthropometric, physiological, or psychological requirements of the men who will use them.

Hunting—Fluctuation about a midpoint due to instability, as oscillations of the needle of an instrument about a median value.

Hydromagnetics—See Magnetohydrodynamics.

Hypersonic—1. Pertaining to hypersonic flow. 2. Pertaining to speeds of Mach 5 or greater.

Hypersonic Flow—In aerodynamics, flow of a fluid over a body at speeds much greater than the speed of sound and in which the shock waves start at a finite distance from the surface of the body.

Hypoxia—Oxygen deficiency in the blood, cells, or tissues of the body in such degree as to cause psychological and physiological disturbances.

Hypoxia may result from a scarcity of oxygen in the air being breathed, or from an inability of the body tissues to absorb oxygen under conditions of low ambient pressure. In the latter case, water vapors from body fluids increase in the sacs of the lungs, crowding out the oxygen.

I

Igniter—Any device used to begin combustion, such as a spark plug in the combustion chamber of a jet engine, or a squib used to ignite fuel in a rocket.

Impact Area—The area in which a rocket strikes the earth's surface.

Used specifically in reference to the "impact
of a rocket range.

Impact Bag—An inflatable bag attached to a spacecraft or reentry capsule to absorb part of the shock of landing.

Inertial Guidance—Guidance by means of acceleration measured and integrated within the craft.

Infrared—Infrared radiation; electromagnetic radiation in the wavelength interval from the red end of the visible spectrum on the lower limit to microwaves used in radar on the upper limit.

Infrared Radiation (abbr IR)—Electromagnetic radiation lying in the wavelength interval from about 0.8 microns to an indefinite upper boundary sometimes arbitrarily set at 1,000 microns (0.01 cm). Also called "black light," "long wave radiation."

At the lower limit of this interval, the infrared radiation spectrum is bounded by visible radiation, while on its upper limit it is bounded by microwave radiation of the type important in radar technology.

Whereas visible radiation is generated primarily by intra-atomic processes, infrared radiation is generated almost wholly by larger-scale intramolecular processes, chiefly molecular rotations and internal vibrations of many types. Electrically symmetric molecules, such as the nitrogen and oxygen molecules which comprise most of the earth's atmosphere, are not capable of absorbing or emitting infrared radiation, but several of the triatomic gases, such as water vapor, carbon doxide, and ozone are infrared-active and play important roles in the propagation of infrared radiation in the atmosphere.

Since a black body at terrestrial temperature radiates with maximum intensity in the spectrum (near 10 microns), there exists a complex system of infrared radiation currents within our atmosphere.

Injection—1. The introduction of fuel, fuel and air, fuel and oxidizer, water, or other substance into an engine induction system or combustion chamber. 2. The process of putting an artificial satellite into orbit. 3. The time following launching when non-gravitational forces (thrust, lift, and drag) become negligible in their effect on the trajectory of a space vehicle.

More than one injection is possible in a single flight if engines are stopped and restarted.

Insertion—The process of putting an artificial satellite into orbit. Also the time of such action.

Intensity—1. In general, the degree or amount, usually expressed by the elemental time rate or spatial distribution, of some condition or physical quantity, such as electric field, sound, magnetism, etc.

2. With respect to electromagnetic radiation, a measure of the radiant flux per unit solid angle emanating from some source. Frequently, it is desirable to specify this as radiant intensity in order to clearly distinguish it from luminous intensity.

Interface—The junction points or the points within or between systems or subsystems where matching or accommodation must be properly achieved in order to make their operation compatible with the successful operation of all other functional entities in the space vehicle and its ground support.

International Geophysical Year (abbr IGY)—By international agreement, a period during which greatly increased observation of world-wide geophysical phenomena is undertaken through the cooperative effort of participating nations. July 1957-December 1958 was the first such "year"; however, precedent was set by the International Polar Years of 1882 and 1921.

International Year of the Quiet Sun (abbr IQSY)—The international program for maximum observation and research in connection with expected period of low solar activity between April 1964 and December 1965.

Ion—An atom or molecularly bound group of atoms having an electric charge. Sometimes also a free electron or other charged subatomic particle.

Ionic Propulsion (electrostatic propulsion)—Rocket propulsion using the THRUST furnished by electrically accelerated ions. Much higher SPECIFIC IMPULSES and EXHAUST VELOCITIES may be obtained than with chemical propulsion, but current laboratory versions of the ionic rocket are capable of furnishing a total thrust of only a few ounces.

Ionosphere—The atmospheric shell characterized by a high ion density. Its base is at about 70 or 80 km and it extends to an indefinite height.

The ionosphere is classically subdivided into "layers." Each "layer," except the D-layer, is supposedly characterized by a more or less regular maximum of electron density.

D-layer.—The D-layer exists only in the daytime. It is not strictly a layer at all, since it does not exhibit a peak of electron or ion density, but is rather a region of increasing electron and ion density, starting at about 70 to 80 km and merging with the bottom of the E-layer.

The lowest clearly defined layer is the E-layer, occurring between 100 and 120 km. The F_1-layer and F_2-layer occur in the general region between 150 and 300 km, the F_2-layer being always present and having the higher electron density. The existence of a G-layer has been suggested, but is questionable. The portions of the ionosphere in which these "layers" tend to form are known as ionospheric "regions," as in "D-region," "E-region," "F-region," "G-region."

Sudden increases in ionization are referred to as "sporadic," as in "sporadic E" or "sporadic D."

The above assumption that the ionosphere is stratified in the vertical into discrete layers is currently under serious question. Some evidence supports a belief that ion clouds are the basic elements of the ionosphere. Other investigations appear to reveal the ionosphere as a generally ionized region characterized by more or less random fluctuations of electron density.

Isotropic—In general, pertaining to a state which a quantity or spatial derivatives thereof are independent of direction.

IQSY—See International Year of the Quiet Sun.

J

Jerk—A vector that specifies the time rate of change of an acceleration; the third derivative of displacement with respect to time.

Joule's Constant—The ratio between heat and work units from experiments based on the first law of thermodynamics: 4.186 x 10^7 ergs/cal. Also called "mechanical equivalent of heat."

K

Kelvin Temperature Scale (abbr K)—An absolute temperature scale independent of the thermometric properties of the working substance. On this scale, the difference between two temperatures T_1 and T_2 is proportional to the heat converted into mechanical work by a Carnot engine operating between the isotherms and adiabats through T_1 and T_2. Also called "absolute temperature scale," "thermodynamic temperature scale."

For convenience the Kelvin degree is identified with the Celsius degree. The ice point in the Kelvin scale is 273.16°K. See **Absolute Zero.**

Kepler's Laws—The three empirical laws describing the motions of planets in their orbits, discovered by Johannes Kepler (1571-1630). These are: (1) The orbits of the planets are ellipses, with the sun at a common focus. (2) As a planet moves in its orbit, the line joining the planet and sun sweeps over equal areas in equal intervals of time. Also called "law of equal areas." (3) The squares of the periods of revolution of any two planets are proportional to the cubes of their mean distances from the sun.

Kev—A unit of energy, one thousand electron volts.

Kirchhoff's Law—The radiation law which states that at a given temperature the ratio of the emissivity to the absorptivity for a given wavelength is the same for all bodies and is equal to the emissivity of an ideal black body at that temperature and wavelength.

Loosely put, this important law asserts that good absorbers of a given wavelength are also good emitters of that wavelength. It is essential to note that Kirchhoff's law relates absorption and emission at the same wavelength and at the same temperature. Also called "Kirchhoff's radiation law."

L

Laser—(From light amplification by stimulated emission of radiation.) A device for producing light by emission of energy stored in a molecular or atomic system when simulated by an input signal.

Launch Pad—The load-bearing base or platform from which a rocket vehicle is launched. Usually called "pad."

Launch Ring—The metal ring on the launch pad on which a missile stands before launch.

Launch Vehicle—Any device which propels and guides a spacecraft into orbit about the earth or into a trajectory to another celestial body: Often called "booster."

Launch Window—An interval of time during which a rocket can be launched to accomplish a particular purpose as "lift-off occurred 5 minutes after the beginning of the 82-minute launch window."

Libration—A real or apparent oscillatory motion, particularly the apparent oscillation of the moon.

Because of libration, more than half of the moon's surface is revealed to an observer on the earth, even though the same side of the moon is always toward the earth because the moon's periods of rotation and revolution are the same.

Lift-off—The action of a rocket vehicle as it separates from its launch pad in a vertical ascent.

A lift-off is applicable only to vertical ascent; a take-off is applicable to ascent at any angle. A lift-off is action performed by a rocket; a launch is action performed upon a rocket or upon a satellite or spaceship carried by a rocket.

Light Year—The distance light travels in one year at rate of 186,000 miles per second (300,000 kilometers per second.) Equal to 5.9 × 10^{12} miles. See PARSEC.)

Line of Position—In navigation, a line representing all possible locations of a craft at a given instant.

In space this concept can be extended to "sphere of position," "plane of position," etc.

Liquid-Propellant Rocket Engine—A rocket engine fueled with propellant or propellants in liquid form. Also called "liquid-propellant rocket."

Rocket engines of this kind vary somewhat in complexity, but they consist essentially of one or more combustion chambers together with the necessary pipes, values, pumps, injectors, etc.

Local Vertical—At a particular point, the direction in which the force of gravity acts.

Longitudinal Axis—The fore-and-aft line through the center of gravity of a craft.

Longitudinal Vibration—Vibration in which the direction of motion of the particles is the same as the direction of advance of the vibratory motion.

This is in contrast with transverse vibration, in which the direction of motion is pependicular to that of advance.

Lox—1. Liquid oxygen. Used attributively as in "lox tank," "lox unit." Also called "loxygen." 2. To load the fuel tanks of a rocket vehicle with liquid oxygen. Hence, "loxing."

Lunar Atmospheric Tide—An atmospheric tide due to the gravitational attraction of the moon. The only detectable components are the 12-lunar-hour or semidiurnal, as in the oceanic tides, and two others of very nearly the same period. The amplitude of this atmospheric tide is so small that it is detected only by careful statistical analysis of a long record, being about 0.06 mb in the tropics and 0.02 mb in the middle latitudes.

Lyman Alpha Radiation—Ultraviolet radiation at a wavelength of 1216 Å emitted by atomic hydrogen when it passes from its first excited electronic state to its ground state. Light of this short wavelength is not transmitted by the earth's atmosphere, and a study of this extremely important line in the sun's spectrum was made only with the advent of rocket and satellite astronomy. The Lyman alpha transition is the longest wavelength member of the Lyman series of atomic hydrogen, and the strongest ultraviolet line emitted by the sun.

M

Mach Number—(After Ernst Mach (1838-1916), Austrian scientist.) A number expressing the ratio of the speed of a body or of a point on a body with respect to the surrounding air or other fluid, or the speed of a flow, to the speed of sound in the medium; the speed represented by this number.

If the Mach number is less than one, the flow is called "subsonic" and local disturbances can propagate ahead of the flow. If the Mach number is greater than one, the flow is called "supersonic" and disturbance cannot propagate ahead of the flow, with the result that shock waves form.

Magnetic Storm—[illegible] worldwide disturbance of the earth's **magnetic fie[illegible].**

Magnetic storms are frequently characterized by a sudden onset, in which the magnetic field undergoes marked changes in the course of an hour or less, followed by a very gradual return to normality, which may take several days. Magnetic storms are caused by solar disturbances, though the exact nature of the link between the solar and terrestrial disturbances is not understood. Sometimes a magnetic storm can be linked to a particular solar disturbance. In these cases, the time between solar flare and onset of the magnetic storm is about one or two days, suggesting that the disturbance is carried to the earth by a cloud of particles thrown out by the sun.

Magnetohydrodynamics—The study of the interaction that exists between a magnetic field and an electrically conducting fluid. Also called "magnetoplasmadynamics," "magnetogasdynamics," "hydromagnetics," "MHD."

Magnetometer—An instrument used in the study of geomagnetism for measuring any magnetic element.

Magnetosphere—That part of the earth's atmosphere which exists by virtue of the earth's magnetic field. The magnetosphere consists of trapped particles, mainly electrons and protons, which spiral about the magnetic lines of force from pole to pole, and gradually precess eastward or westward, depending on their charge. Particles are lost by the magnetosphere when they descend into the atmosphere at high latitudes. It is believed that particles are fed into the magnetosphere by effects associated with the arrival of PLASMA clouds ejected during SOLAR FLARES as well as from the beta decay of neutrons produced by COSMIC RAYS striking the upper atmosphere. Particles may also be injected into the magnetosphere by high altitude nuclear explosions. (See VAN ALLEN BELTS.)

Magnitude—Relative brightness of a celestial body. The smaller the magnitude number, the brighter the body.

Decrease of light by a factor of 100 increases the stellar magnitude by 5.00; hence the brightest objects have negative magnitudes. (Sun: −26.8; mean full moon; −12.5; Venus at brightest: −4.3; Jupiter at opposition: −2.3; Sirius: −1.6; Vega: +0.2; Polaris: +2.1). The faintest stars visible to the Naked eye on a clear dark night are of about the sixth magnitude.

Main Bang—Within a radar system, the transmitted pulse.

Main Stage—1. In a multistage rocket, the stage that develops the greatest amount of thrust, with or without booster engines. 2. In a single-stage rocket vehicle powered by one or more engines, the period when full thrust (at or above 90 percent) is attained. 3. A sustainer engine, considered as a stage after booster engines have fallen away, as in "the main stage of the Atlas."

Manometer—An instrument for measuring pressure of gases and vapors both above and below atmospheric pressure.

Maria—The large, darker areas, of generally circular outline on the lunar surface. It has been suggested that they are caused by lava flow following the impact of large meteorites during the last stages of formation of the moon.

Mariner—The initial unmanned exploration of the planets is being conducted in the United States under the Mariner program. Mariner 2, launched August 26, 1962, passed within 21,000 miles of Venus on December 14, 1962, and radioed to earth information concerning the infrared and microwave emission of the planet, and the strength of the planet's magnetic field. Future flyby missions to both Venus and Mars are planned.

Mars I— An instrumented spacecraft launched by the Soviet Union on November 1, 1962, designed to

investigate the interplanetary medium and transmit photographs of Mars to the earth. It is programmed to pass the planet in June, 1963, when it will be at a distance of 150 million miles.

Maser—An amplifier utilizing the principle of microwave amplification by stimulated emission of radiation. Emission of energy stored in a molecular or atomic system by a microwave power supply is stimulated by the input signal.

Mass—The measure of the amount of matter in a body, thus its inertia.

The weight of a body is the force with which it is attracted by the earth.

Mass-Energy Equivalence—The equivalence of a quantity of mass m and a quantity of energy E, the two quantities being related by the mass-energy relation, $E = mc^2$, where c = the speed of light.

Mass Ratio—The ratio of the mass of the propellant charge of a rocket to the total mass of the rocket charged with the propellant.

Mate—To fit together two major components of a system.

Mean Free Path—Of any particle, the average distance that a particle travels between successive collisions with the other particles of an ensemble.

Mechanoreceptor—A nerve ending that reacts to mechanical stimuli, as touch, tension, and acceleration.

Mega—A prefix meaning multiplied by one million as in "megacycles."

Memory—The component of a computer, control system, guidance system, instrumented satellite, or the like designed to provide ready access to data or instructions previously recorded so as to make them bear upon an immediate problem, such as the guidance of a physical object, or the analysis and reduction of data.

Mercury—The initial man-in-space program of the United States. The first manned sub-orbital flight took place on April 23, 1961, and the first orbital mission on February 20, 1962. Two others followed on May 24, 1962 and October 3, 1962. An 18 orbit flight is scheduled for April, 1963.

Mesosphere—1. The atmospheric shell between about 20 km and about 70 or 80 km, extending from the top of the stratosphere to the upper temperature minimum (the mesopause.) It is characterized by a broad temperature maximum (the mesopeak) at about 50 km, except possibly over the winter polar regions.

2. The atmospheric shell between the top of the ionosphere (the top of this region has never been clearly defined) and the bottom of the exosphere. (This definition has not gained general acceptance.)

Meteor—In particular, the light phenomenon which results from the entry into the earth's atmosphere of a solid particle from space: more generally, any physical object or phenomenon associated with such an event.

Meteoric—Of or pertaining to meteors, or meteoroids.

Meteorite—A meteoroid which has reached the surface of the earth without being completely vaporized.

Meteorid—A solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom or molecule.

Meteorological Rocket—A rocket designed primarily for routine upper-air observation (as opposed to research) in the lower 250,000 feet of the atmosphere, especially that portion inaccessible to balloons, i.e., above 100,000 feet. Also called "rocketsonde."

MEV—A unit of energy, one million electron volts.

Micro—1. A prefix meaning divided by one million. 2. A prefix meaning very small as in "micrometeorite."

Microbar (abbr μb)—The unit of pressure in the c.g.s. system and equal to one dyne per square centimeter.

Micrometeorite—A very small meteorite or meteoritic particle with a diameter in general less than a millimeter.

Micron—One millionth of a meter, abbreviated μ.

Microwave Region—Commonly, that region of the radio spectrum between approximately 1000 Mc and 300,000 Mc.

Corresponding wavelengths are 30 cm to 1 mm.

The limits of the microwave region are not clearly defined but in general it is considered to be the region in which radar operates.

Millibar—A unit of pressure equal to 1,000 dynes per square centimeter, or 1/1,000 of a bar.

The millibar is used as a unit of measure of atmospheric pressure, a standard atmosphere being equal to 1,013.25 millibars or 29.92 inches of mercury.

Mini.—A contraction of "minitaure" used in combination, as in "minicomponent," "miniradio," "minitransistor."

Miniaturize—To construct a functioning miniature of a part or instrument. Said of telemetering instruments or parts used in an earth satellite or rocket vehicle, where room is at a premium. Hence, "miniaturized," "miniaturization."

Minimum Ionizing Speed—The speed with which a free electron must move through a given gas to be able to ionize gas atoms or molecules by collision. In air at standard conditions, this speed is about 10^7 cm/sec.

Minitrack—A satellite tracking system consisting of a field of separate antennas and associated receiving equipment interconnected so as to form interferometers which track a transmitting beacon in the satellite itself.

Missile—Any object thrown, dropped, fired, launched, or otherwise projected with the purpose of striking a target. Short for "ballistic missile," "guided missile."

Missile is loosely used as a synonym for "rocket" or "spacecraft" by some careless writers.

Mock-Up—A full-sized replica or dummy of something, such as a spacecraft, often made of some substitute material, such as wood, and sometimes incorporating functioning pieces of equipment, such as engines.

Mode of Propagation—In transmission, a form of propagation of guided waves that is characterized by a particular field pattern in a plane transversed to the direction of propagation, which field pattern is independent of position along the axis of the waveguide.

In the case of uniconductor waveguides the field pattern of a particular mode of propagation is also independent of frequency.

Mode of Vibration—In a system undergoing vibration, a characteristic pattern assumed by the system, in which the motion of every particle is simple harmonic with the same frequency.

Two or more modes of vibration may exist concurrently in a multiple-degree-of-freedom system.

Modulation—Specifically, vibration of some characteristic of a radio wave, called the "carrier wave," in accordance with instantaneous values of another wave, called the "modulating wave."

Variation of amplitude is amplitude modulation, variation of frequency is frequency modulation, and variation of phase is phase modulation. The formation of very short bursts of a carrier wave, separated by relatively long periods during which no carrier wave is transmitted, is pulse modulation.

Module—1. A self-contained unit of a launch vehicle or spacecraft which serves as a building block for the overall structure. The module is usually designated by its primary function as "command module," "lunar landing module," etc. 2. A one-package assembly of functionally associated electronic parts; usually a plug-in unit.

Module—An aggregate of two or more atoms of a substance that exists as a unit.

Molecule—An aggregate of two or more atoms of a substance that exists as a unit.

Moment (abbr M)—A tendency to cause rotation about a point or axis, as of a control surface about its hinge or of an airplane about its center of gravity; the measure of this tendency, equal to the product of the force and the perpendicular distance between the point of axis of rotation and the line of action of the force.

Moment of Inertia (abbr I)—Of a body about an axis, the Σmr^2, where m is the mass of a particle of the body and r its distance from the axis.

Momentum—Quantity of motion.

Linear momentum is the quantity obtained by multiplying the mass of a body by its linear speed. Angular momentum is the quantity obtained by multiplying the moment of inertia of a body by its angular speed.

The momentum of a system of particles is given by the sum of the moments of the individual particles which make up the system, or by the product of the total mass of the system and the velocity of the center of gravity of the system.

The momentum of a continuous medium is given by the integral of the velocity over the mass of the medium, or by the product of the total mass of the medium and the velocity of the center of gravity of the medium.

Monopropellant—A rocket propellant consisting of a single substance, especially a liquid, capable of producing a heated jet without the addition of a second substance.

M-Region—Name given to a region of activity on the sun when the nature of that activity cannot be determined.

The M-region used in accounting for recurrent magnetic storms with a period the same as the period of solar rotation relative to the earth, 27.3 days. See **Magnetic Storms.**

Multiplexer—A mechanical or electrical device for sharing of a circuit by two or more coincident signals.

Multiplexing—The simultaneous transmission of two or more signals within a single channel.

The three basic methods of multiplexing involve the separation of signals by time division, frequency division, and phase division.

Multipropellant—A rocket propellant consisting of two or more substances fed separately to the combustion chamber.

Multistage Rocket—A vehicle having two or more rocket units, each unit firing after the one in back of it has exhausted its propellant. Normally, each unit, or stage, is jettisoned after completing its firing. Also called a "multiple-stage rocket" or, infrequently, a "step rocket."

Musa Antenna—A "multiple-unit steerable antenna" consisting of a number of stationary antennas, the composite major lobe of which is electrically steerable.

N

NACA (abbr)—National Advisory Committee of Aeronautics.

Nano—A prefix meaning divided by one billion, as in "nanosecond," one billionth of a second.

Nanosecond (abbr nsec)—10^{-9} second. Also called "millimicrosecond."

NASA (abbr)—National Aeronautics and Space Administration.

NASC (abbr)—National Aeronautics and Space Council.

Natural Frequency—1. The frequency of free oscillation of a system. For a multiple-degree-of-freedom system, the natural frequencies are the frequencies of the normal modes of vibration. 2. The undamped resonant frequency of the rotor gimbal and its elastic restraint. It is expressed in cycles per unit time. 3. Specifically, of a gyro.

Nautical Mile—A unit of distance used principally in navigation. For practical navigation it is usually considered the length of one minute of any great circle of the earth, the meridian being the great circle most commonly used. Also called "sea mile." By international agreement of 1 July 1959, U.S., Great Britain and nearly all maritime nations established the International Nautical Mile, equal to exactly 1852 meters. Using the yard-meter conversion factor effective July 1, 1959, the International Nautical Mile is equivalent to 6,076.11549 international feet.

NASA's Designated Representative—A representative of the NASA installation stationed at supplier's plant or a representative of the inspection agency to whom quality assurance functions have been delegated.

NASA Installation—A major organization unit of the NASA; includes Headquarters and field installations. Field installations are assigned specific missions in the NASA space program.

Neutron—A subatomic particle with no electric charge, and with a mass slightly more than the mass of the proton.

Protons and neutrons comprise atomic nuclei; and they are both classed as nucleons.

Neutrosphere—The atmospheric shell from the earth's surface upward in which the atmospheric constituents are for the most part un-ionized, i.e., electrically neutral.

The region of transition between the neutrosphere and the ionosphere is somewhere between 70 and 90 km, depending on latitude and season.

Newton's laws of motion—A set of three fundamental postulates forming the basis of the mechanics of rigid bodies, formulated by Newton in 1687.

The first law is concerned with the principle of inertia and states that if a body in motion is not acted upon by an external force, its momentum remains constant (law of conservation of momentum.) The second law asserts that the rate of change of momentum of a body is proportional to the force acting upon the body and is the direction of the applied force. A familiar statement of this is the equation

$$F = ma$$

Where F is vector sum of the applied forces, m the mass, and a the vector acceleration of the body. The third law is the principle of action and reaction, stating that for every force acting upon a body there exists a corresponding force of the same magnitude exerted by the body in the opposite direction.

Noctilucent Clouds—Rarely observed clouds of unknown composition which occur at great height. Photometric measurements have located them between 75 and 90 km. They resemble thin cirrus, but usually with a bluish or silverish color, although sometimes orange to red, standing out against a dark night sky. Sometimes called "luminous clouds."

Node—1. One of the two points of intersection of the orbit of a planet, planetoid, or comet with the ecliptic, or of the orbit of a satellite with the plane of the orbit of its primary. Also called "nodal point."

That point at which the body crosses to the north side of the reference plane is called the ascending node; the other, the descending node. The line connecting the nodes is called line of nodes.

2. A point, line, or surface in a standing wave where some characteristic of the wave has essentially zero amplitude.

The appropriate modifier should be used before the word "node" to signify the type that is intended; e.g., displacement node, velocity node, pressure node.

3. A terminal of any branch of a network or a terminal common to two or more branches of a network. Also called "junction point," "branch point," or "vertex."

Noise—1. Any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. When caused by natural electrical discharges in the atmosphere noise may be called "static."

2. An erratic, intermittent, or statistically random oscillation.

If ambiguity exists as to the nature of the noise, a phrase such as "acoustic noise" or "electric noise" should be used.

Since the above definitions are not mutually exclusive, it is usually necessary to depend upon context for distinction.

Nonrelativistic Particles—Particles which possess a velocity small with respect to that of light, which is 186,000 miles/second or 3×10^{10} centimeters per second. (See RELATIVISTIC PARTICLES.)

Nonthermal Radiation—Electromagnetic radiation emitted by accelerated charged particles not in thermal equilibrium. The distribution of energy with frequency of nonthermal radiation usually differs from that of blackbody or THERMAL RADIATION. CYCLOTRON and SYNCHROTRON RADIATION of charged particles in magnetic fields are examples of nonthermal radiation, as is the light from a fluorescent lamp or the AURORA.

Normal Mode of Vibration—A mode of free vibration of an undamped system. In general, any composite motion of a vibrating system is analyzable into a summation of its normal modes, also called natural mode, "characteristic mode," and "eigen mode."

Normal Shock Wave—A shock wave perpendicular, or substantially so, to the direction of flow in a supersonic flow field. Sometimes shortened to "normal shock."

Nosecone—The cone-shaped leading end of a rocket vehicle, consisting of (a) a chamber or chambers in which a satellite, instruments, animals, plants, or auxiliary equipment may be carried, and (b) an outer surface built to withstand high temperatures generated by aerodynamic heating.

In a satellite vehicle, the nosecone may become the satellite itself after separating from the final stage of the rocket or it may be used to shield the satellite until orbital speed is accomplished, then separating from the satellite. See **Shroud.**

Nozzle—Specifically, the part of a rocket thrust chamber assembly in which the gases produced in the chamber are accelerated to high velocities.

Nuclear Fuel—Fissionable material of reasonably long life, used or usable in producing energy in a nuclear reactor.

Nuclear Radiation—The emission of neutrons and other particles from an atomic nucleus as the result of nuclear fission or nuclear fusion.

Nuclear Reactor—An apparatus in which nuclear fission may be sustained in self-supporting chain reaction. Commonly called "reactor."

Nucleosynthesis—The production of the various elements occurring in nature out of hydrogen nuclei or protons. Examples of nucleosynthesis are: thermonuclear reactions in stars and interactions involving fast, charged particles (COSMIC RAYS) near stars or in the interstellar medium.

Nucleus—The positively charged core of an atom with which is associated practically the whole mass of the atom but only a minute part of its volume.

A nucleus is composed of one or more protons and an approximately equal number of neutrons.

O

OAO—The Orbiting Astronomical Observatory which will make possible telescopic observations in the infrared, visible, ultraviolet, and x-ray regions from a stabilized platform above the obscuring effects of the earth's atmosphere. The first OAO will be launched using an ATLAS-AGENA by the United States late in 1963 or early in 1964, with successive flights at six-month intervals.

Occultation—The disappearance of a body behind another body of larger apparent size.

When the moon passes between the observer and a star, the star is said to be occulted.

Octave—The interval between any two frequencies having the ratio of 1:2.

The interval in octaves between any two frequencies is the logarithm to the base 2 (or 3.322 times the logarithm to the base 10) of the frequency ratio.

Oculogravic Illusion—The apparent displacement of an object in space caused by the difference which may exist between the direction of the vertical and that of resultant g.

Oculogyral Illusion—The apparent movement of an object in the same direction as that in which one seems to be turning when the semicircular canals of the inner ear are stimulated.

OGO—The Orbiting Geophysical Observatory will be a standardized satellite designed to undertake a large variety of geophysical experiments, including investigations of the MAGNETOSPHERE, the earth's magnetic field, MICROMETEORITES, and radio propagation. The first launching using an ATLAS-AGENA is scheduled by the United States for 1963, the following for 1964.

Orbit—1. The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves. 2. To go around the earth or other body in an orbit.

Orbital Elements—A set of 7 parameters defining the orbit of a satellite.

Orbital Period—The interval between successive passages of a satellite.

Orbital Velocity—1. The average velocity at which an earth satellite or other orbiting body travels around its primary. 2. The velocity of such a body at any given point in its orbit, as in "its orbital velocity at the apogee is less than at the perigee."

Order of Magnitude—A factor of 10.

Two quantities of the same kind which differ by less than a factor of 10 are said to be of the same order of magnitude. "Order of magnitude" is used loosely by many writers to mean a pronounced difference in quantity but with the difference much less or much more than a factor of 10.

Orthogonal—At right angles.

OSO—The Orbiting Solar Observatory. OSO I was launched by the United States on March 7, 1962. It is designed in particular to gather information on the emission by the sun of x and y rays, ultraviolet light, neutrons, protons, and electrons which cannot be obtained from the earth's surface. A second similar OSO will be launched in 1963, with improved versions following.

Otolith—A small calcareous concretion located in the inner ear which plays a part in the mechanism of orientation.

Outgassing—The evolution of gas from a solid in a vacuum.

Oxidizer—Specifically, a substance (not necessarily containing oxygen) that supports the combustion of a fuel or propellant.

OZONE—The molecule O_3. It is produced in the upper STRATOSPHERE by the PHOTODISSOCIATION of O_2 and subsequent union of O and O_3. Ozone absorbs ultraviolet strongly in the wavelength region from 2000 to 3000 A.

Ozonosphere—The general stratum of the upper atmosphere in which there is an appreciable ozone concentration and in which ozone plays an important part in the radiative balance of the atmosphere. This region lies roughly between 10 and 50 km, with maximum ozone concentration at about 20 to 25 km. Also called 'ozone layer.'

P

Pad = Launch Pad.

Paraglider—A flexible-winged, kite-like vehicle designed for use in a recovery system for launch vehicles or as a reentry vehicle.

Parameter—1. In general, any quantity of a problem that is not an independent variable. More specifically, the term is often used to distinguish, from dependent variables, quantities which may be more or less arbitrarily assigned values for purposes of the problem at hand. 2. In statistical terminology, any numerical constant derived from a population or a probability distribution. Specifically, it is an arbitrary constant in the mathematical expression of a probability distribution.

Parsec—A unit of distance commonly used to measure interstellar dimensions. It is the distance at which an ASTRONOMICAL UNIT, the mean distance of the earth from the sun, would subtend an angle of one second of an arc. A parsec equals 3.26 LIGHT YEARS.

Part—An element of a component, assembly or subassembly which is not normally subject to further subdivision or disassembly or maintenance purposes. Examples are: resistors, transformers, electron tubes, relays, etc.

Passive—Reflecting a signal without transmission, as "Echo is a passive satellite." Contrasted with "active."

Payload—1. Originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc. 2. By extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle during its flight.

Peri—A prefix meaning near, as in "perigee."

Perigee—That orbital point nearest the earth when the earth is the center of attraction.

That orbital point farthest from the earth is called "apogee." Perigee and apogee are used by many writers in referring to orbits of satellites, especially artificial satellites, around any planet or satellite, thus avoiding coinage of new terms for each planet and moon.

Perihelion—For an elliptic orbit about the sun, the point closest to the sun.

Pencil-Beam Antenna.—A unidirectional antenna, so designed that cross sections of the major lobe by planes perpendicular to the direction of maximum radiation are approximately circular.

Perihelion—That orbital point nearest the sun when the sun is the center of attraction.

That orbital point farthest from the sun is called "aphelion." The term "perihelion" should not be confused with "parhelion," a form of halo.

Period—The interval needed to complete a cycle. Often used in reference to time of complete orbit.

Perturbation—Specifically, a disturbance in the regular motion of a celestial body, the result of a force additional to those which cause the regular motion.

Photodissociation—The removal of one or more atoms from a molecule by the absorption of a quantum of electromagnetic or photon energy. The energy of the photon absorbed by a system such as an atom or molecule increases in direct proportion to the frequency of the radiation. Simple molecules such as O_2, N_2, CO_2, H_2O which are the primary molecular constituents of the atmosphere can only be photodissociated by ultraviolet or higher frequency (shorter wavelength) light. They are not dissociated by visible light. (See PHOTOIONIZATION.)

Photoionization—The removal of one or more electrons from an atom or molecule by the absorption of a photon. As with PHOTODISSOCIATION, ultraviolet or shorter wavelength light is required to photoionize simple molecules.

Photon—According to the quantum theory of radiation, the elementary quantity, or "quantum" of radiant energy. It is regarded as a discrete quantity having a mass equal to hv/c^2, where h is Planck's constant, v the frequency of radiation, and c the speed of light in a vacuum.

Photon Engine—A projected type of reaction engine in which thrust would be obtained from a stream of electromagnetic radiation.

Although the thrust of this engine would be minute, it may be possible to apply it for extended periods of time. Theoretically, in space, where no resistance is offered by air particles, very high speeds may be built up.

Photosphere—The intensely bright portion of the sun visible to the unaided eye. The photosphere is that portion of the sun's atmosphere which emits the continuous radiation upon which the Fraunhofer lines are superimposed. In one sun model, the photosphere is thought to be below the reversing layer in which Fraunhofer absorption takes place. In another model, all strata are considered equally effective in producing continuous emissions and line absorption.

Physiological acceleration—The acceleration experienced by a human or an animal test subject in an accelerating vehicle.

Pickoff—A sensing device, used in combination with a gyroscope in an automatic pilot or other automatic or robot apparatus, that responds to angular movement to create a signal or to effect some type of control.

Pickup—1. A device that converts a sound, scene, or other form of intelligence into corresponding electric signals (e.g., a microphone, a television camera, or a phonograph pickup.) 2. The minimum current, voltage, power, or other value at which a relay will complete its intended function. 3. Interference from a nearby circuit or system.

Pico—A prefix meaning divided by one million million.

Pioneer—A series of DEEP SPACE PROBES designed to investigate the interplanetary medium. Pioneer I, launched October 11, 1959, determined the radial extent of the earth's MAGNETOSPHERE, and made the first determination of the density of MICROMETEORITES in space. Pioneer 5, launched March 11, 1960 made the first measurements of the effects of a SOLAR FLARE far from the earth's magnetic field, and established a record of radio communication of 22.5 million miles, since exceeded only by MARINER 2.

Pip—Signal indication on the scope of an electronic instrument, produced by a short, sharply peaked pulse of voltage. Also called "blip."

Pitchover—The programed turn from the vertical that a rocket under power takes as it describes an arc and points in a direction other than vertical.

Plages—Clouds of calcium or hydrogen vapor that show up as bright patches on the visible surface of the sun.

Planck's Constant (abbr h)—A constant, usually designated h, of dimensions mass x length^2 x time $^{-1}$ equal to 6.6252 x 10^{-27} erg sec. It scales the energy of electromagnetic radiation of frequency v such that the radiation appears only in quanta nhv, n being an integer.

Planck's Law—An expression for the variation of monochromatic emittance (emissive power) as a function of wavelength of black-body radiation at a given temperature; it is the most fundamental of the radiation laws.

Planet—A celestial body of the solar system, revolving around the sun in a nearly circular orbit, or a similar body revolving around a star.

The larger of such bodies are sometimes called "principal planets" to distinguish them from asteroids, planetoids, or minor planets, which are comparatively very small.

An inferior planet has an orbit smaller than that of the earth; a superior planet has an orbit larger than that of the earth. The four planets nearest the sun are called "inner planets"; the others, "outer planets." The four largest planets are called "major planets." The world "planet" is of Greek origin meaning, literally, wanderer, applied because the planets appear to move relative to the stars.

Plasma—An electrically conductive gas comprised of neutral particles, ionized particles, and free electrons but which, taken as a whole, is electrically neutral.

A plasma is further characterized by relatively large intermolecular distances, large amounts of energy stored in the internal energy levels of the particles and by the presence of a plasma sheath at all boundaries of the plasma.

Plasmas are sometimes referred, to as a fourth state of matter.

Plasma Engine—A reaction engine using magnetically accelerated plasma as propellant.

A plasma engine is a type of electrical engine.

Plasma Jet—A magnetohydrodynamic rocket engine in which the ejection of plasma generates thrust.

Plasma Sheath—1. The boundary layer of charged particles between a plasma and its surrounding walls, electrodes, or other plasmas.

The sheath is generated by the interaction of the plasma with the boundary material. Current flow may be in only one direction across the sheath (single sheath), in both directions across the sheath (double sheath), or when the plasma is immersed in a magnetic field, may flow along the sheath surface at right angles to the magnetic field (magnetic current sheath.)

2. An envelope of ionized gas that surrounds a body moving through an atmosphere at hypersonic velocities.

The plasma sheath affects transmission, reception, and diffraction of radio waves; thus is important in operational problems of spacecraft, especially during reentry.

Pod—An enclosure, housing, or detachable container of some kind, as: (a) an engine pod, (b) an ejection capsule.

Polarization—1. The state of electromagnetic radiation when transverse vibrations take place in some regular manner, e.g., all in one plane, in a circle, in an ellipse, or in some other definite curve.

Radiation may become polarized because of the nature of its emitting source, as is the case with many types of radar antennas, or because of some processes to which it is subjected after leaving its source, as that which results from the scattering of solar radiation as it passes through the earth's atmosphere.

Posigrade Rocket—An auxiliary rocket which fires in the direction in which the vehicle is pointed, used for example in separating two stages of a vehicle.

Pound (abbr lb)—1. A unit of weight equal in the United States to 0.45359237 kilograms. 2. Specifically, a unit of measurement for the thrust or force of a reaction engine representing the weight the engine can move, with 100,000 pounds of thrust.

Precession—Change in the direction of the axis of rotation of a spinning body, as a gyroscope, when acted upon by a torque.

The direction of motion of the axis is such that it causes the direction of spin of the gyroscope to tend to coincide with that of the impressed torque. The horizontal component of precession is called "drift," and the vertical component is called "topple."

Precession of the Equinoxes—The conical motion of the earth's axis about the vertical to the plane of the ecliptic, caused by the attractive force of the sun, moon, and other planets on the equatorial protuberance of the earth.

Pressure (abbr p)—As measured in a vacuum system, the quantity measured at a specified time by a so-called vacuum gage, whose sensing element is located in a cavity (gage tube) with an opening oriented in a specified direction at a specified point within the system, assuming a specified calibration factor.

The sensitivity of the sensing element is in general not the same for all molecular species, but the gage reading is frequently reported using the calibration factor for air regardless of the composition of the gas. The opening to the gage tube is often carelessly oriented with respect to mass-flow vectors in the gas (which is seldom at rest), and errors due to variations in wall temperatures of tube and system are frequently neglected. The actual total pressure in a high-vacuum system cannot usually be measured by a single gage, but in vacuum technology the term "total pressure" is sometimes used to refer to the reading of a single untrapped gage which responds to condensable vapors as well as permanent gases.

Pressure Suit—A garment designed to provide the human body an environment above ambient pressure so that respiratory and circulatory functions may continue normally, or nearly so, under low-pressure conditions, such as occur at high altitudes or in space without benefit of a pressurized cabin.

Pressurized—Containing air, or other gas, at a pressure that is higher than the pressure outside the container.

Prestage—A step in the action of igniting a large liquid rocket taken prior to the ignition of the full flow, and consisting of igniting a partial flow of propellants into the thrust chamber.

Primary—1. Short for "primary body." 2. Short for "primary cosmic ray."

Primary Body—The spatial body about which a satellite or other body orbits, or from which it is escaping, or towards which it is falling.

The primary body of the moon is the earth; the primary body of the earth is the sun.

Primary Cosmic Rays—High energy particles originating outside the earth's atmosphere.

Primary cosmic rays appear to come from all directions in space. Their energy appears to range from 10^{9} to more than 10^{18} electron volts.

Probable Error (abbr pe)—In statistics, that value e_p for which there exists an even probability (0.5) that the actual error exceeds e_p. The probable error e_p is 0.6745 times the standard deviation σ.

The probable error is not "probable" in the normal sense of the word.

Probability—The chance that a prescribed event will occur, represented as a number greater than zero but less than one. The probability of an impossible event is zero, and that of an inevitable event is one.

Probe—Any device inserted in an environment for the purpose of obtaining information about the environment. Specifically, an instrumented vehicle moving through the upper atmosphere or space or landing upon another celestial body in order to obtain information about the specific environment.

Almost any instrumented spacecraft can be considered a probe. However, earth satellites are not usually referred to as "probes." Also, almost any instrumented rocket can be considered a probe. In practice, rockets which attain an altitude of less than one earth radius (4000 miles) are called "sounding rockets," those which attain an altitude of more than one earth radius are called "probes" or "space probes." Spacecraft which enter into orbit around the sun are called "deep-space probes." Spacecraft which enter into orbit around the sun are called "deep-space probes." Spacecraft designed to pass near or land on another celestial body are often designated "lunar probe," "Martian probe," "Venus probe," etc.

Prominence—A filamentlike protuberance from the chromosphere of the sun.

Prominences can be observed (optically) whenever the sun's disk is masked, as during an eclipse or using a coronagraph; and can be observed instrumentally by filtering in certain wavelengths, as with a spectroheliograph. A typical prominence is 6,000 to 12,000 km thick, 60,000 km high, and 200,000 km long.

Propellant—Short for "rocket propellant."

Prospector—The successor to the Surveyor program with the mission of obtaining detailed photographs of the lunar surface, SOFT-LANDING mobile, automated laboratories on the moon, and returning lunar soil samples to the earth for analysis.

Proton—A positively-charged subatomic particle having a mass slightly less than that of a neutron but about 1847 times greater than that of an electron. Essentially, the proton is the nucleus of the hydrogen isotope $_1H^1$ (ordinary hydrogen stripped of its orbital electron.) Its electric charge ($+4.8025 \times 10^{-10}$ esu) is numerically equal, but opposite in sign, to that of the electron.

Protons and neutrons comprise atomic nuclei; they are both classed as "nucleons."

Prototype—Spacecraft or element thereof which is undergoing or has passed environmental and other tests which qualify design for fabrication of flight units or elements thereof.

Proving Stand—A test stand for reaction engines, especially rocket engines.

Purge—To rid a line or tank of residual fluid, especially of fuel or oxygen in the tanks or lines of a rocket after a test firing or simulated test firing.

Q

q = **Dynamic Pressure.**

Quantization—The process of converting from continuous values of information to a finite number of discrete values.

Quantum theory—The theory (first stated by Max Planck before the Physical Society of Berlin on December 14, 1900) that all electromagnetic radiation is emitted and absorbed in "quanta" each of magnitude $h\nu$, h being Planck's constant and ν the frequency of the radiation.

Quiet Sun—See "Year of the Quiet Sun."

R

Radar Astronomy—The development of powerful radar transmitters, large antennas, and very sensitive receivers allows the detection of high frequency radio waves (radar) reflected off the nearby members of the solar system. Signals reflected from the moon were first detected in 1945, while the first signals from Venus were unambiguously received in 1961. A careful analysis of the reflected signal gives information as to the distance, velocity of approach or recession, surface roughness, rate of rotation, and dielectric constant of the planet. A large antenna with an aperture of 1000 feet under construction in Puerto Rico should allow radar detection of Mercury, Mars, some of the asteroids, the satellites of Jupiter, and the planet Jupiter itself, if the dense Jovian atmosphere does not absorb all of the incident radar signal.

Radiation—Short for "electromagnetic radiation," "nuclear radiation."

Radiation Belts—See VAN ALLEN BELTS, MAGNETOSPHERE.

Radiation Pressure (abbr Pr)—Pressure exerted upon any material body when electromagnetic radiation is incident upon body.

This pressure is manifested whenever the electromagnetic momentum in a radiation field is changed, and is exactly twice as great when the radiation is reflected at normal incidence as it is when the radiation is entirely absorbed at normal incidence. The magnitude of any radiation pressure effect is directly proportional to the intensity of the radiation, and is very small by most standards.

On a perfectly reflecting surface $Pr = v/3$ where v = radiation density the amount of radiative energy per unit volume in the space above the surface. Radiation pressure has perceptible effect on the orbit of earth satellites, especially those with a large reflecting surface such as Echo.

Radiation Shield—1. A device used on certain types of instruments to prevent unwanted radiation from biasing the measurement of a quantity. 2. A device used to protect bodies from the harmful effects of nuclear radiation, cosmic radiation, or the like.

Radiator—1. Any source of radiant energy, especially electromagnetic radiation. 2. A device that dissipates heat from something, as from water or oil, not necessarily by radiation only.

Generally, the application of the terms "radiator" (in sense 2) or "heat exchanger" to a particular apparatus depends upon the point of view: If the emphasis is upon merely getting rid of heat, "radiator" is most often used, or sometimes "cooler"; if the emphasis is upon transferring heat, "heat exchanger" is used—but these distinctions do not always hold true.

Radio Astronomy—The earth's atmosphere is transparent to electromagnetic radiation in only two frequency bands, or "windows". The familiar "optical window" lies in the wavelength interval from 3000 Å to a few MICRONS. Practically all astronomy and astrophysics prior to thirty years ago was based on the information received through this window. Since that time, the development of sensitive electronic receivers and the construction of large antennas has allowed the detection of radio waves from astronomical sources which pass through the atmosphere in the "radio window," from a wavelength of a few millimeters to a few tens of meters. Radio astronomy has furnished information about the moon, the planets, the sun, the interstellar medium (in particular the distribution of atomic hydrogen), supernova fragments, and the structure of galaxies.

Radiometer—A device used to measure some property of electromagnetic radiation. In the visible and ultraviolet regions of the spectrum, a photocell or photographic plate may be thought of as a radiometer. In the infrared, solid state detectors such as photoconductors, lead sulfide cells and thermocouples are used, while in the radio and microwave regions, vacuum tube receivers, often with parametric or maser preamplifiers, are the most sensitive detectors of electromagnetic radiation.

Radio Meteor—A meteor detected by the reflection of a radio signal from the meteor trail of relatively high ion density (ion column).

Such an ion column is left behind a meteoroid when it reaches the region of the upper atmosphere between about 80 and 120 km, although occasionally radio meteors are detected at higher altitudes.

Radiosonde—A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data.

Radio Telescope—A device for receiving, amplifying, and measuring the intensity of radio waves originating outside the earth's atmosphere.

Ranger—The initial United States program for the investigation of the moon, and the region between the moon and the earth. Early versions of the Ranger are designed to provide closeup television photographs of the lunar surface, and to rough-land seismographs on the moon.

Rarefied Gas Dynamics—The study of the phenomena related to the molecular or noncontinuum nature of gas flow at low densities.

Rayleigh-Jeans Law—An approximation to PLANCK'S LAW for blackbody radiation valid in the limit of long wavelengths. It is almost always of sufficient accuracy in the radio and microwave regions of the spectrum.

Reaction Control System—A system of controlling the attitude of a craft when outside the atmosphere by using jets of gas in lieu of aerodynamic control surfaces.

Reaction Engine—An engine that develops thrust by its reaction to ejection of a substance from it; specifically, such an engine that ejects a jet or stream of gases created by the burning of fuel within the engine.

A reaction engine operates in accordance with Newton's third law of motion, i.e., to every action (force) there is an equal and opposite reaction. Both rocket engines and jet engines are reaction engines.

Readout—1. The action of a radio transmitter transmitting data either instantaneously with the acquisition of the data or by play of a magnetic tape upon which the data have been recorded. 2. In computer operations to extract information from storage.

Readout Station—A recording or receiving radio station at which data are received from a transmitter in a probe, satellite, or other spacecraft.

Real Time—Time in which reporting on events or recording of events is simultaneous with the events.

For example, the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it; the real time of a computer is that time during which it is accepting data.

Recombination—The process by which a positive and a negative ion join to form a neutral molecule or other neutral particle.

Recovery—The procedure or action that obtains when the whole of a satellite, or a satellite instrumentation package, or other part of a rocket vehicle is recovered after a launch; the result of this procedure.

Recycle—In a countdown: To stop the count and to return to an earlier point in the countdown, as in "we have recycled, now at T minus 80 and counting." Compare hold. In testing: to repeat a group or series of tests.

Red Shift—In astronomy, the displacement of observed spectral lines toward the longer wavelengths of the red end of the spectrum. Compare **space reddening.**

The "red shift" in the spectrum of distant galaxies has been interpreted as evidence that the universe is expanding.

Reentry—The event occurring when a spacecraft or other object comes back into the sensible atmosphere after being rocketed to altitudes above the sensible atmosphere; the action involved in this event.

Reentry Vehicle—A space vehicle designed to return with its payload to earth through the sensible atmosphere.

Reentry Window—The area at the limits of the earth's atmosphere through which a spacecraft in a given trajectory can pass to accomplish a successful reentry.

Regenerative Cooling—The cooling of a part of an engine by the propellant being delivered to the combustion chamber; specifically, the cooling of a rocket—engine combustion chamber or nozzle by circulating the fuel or oxidizer, or both, around the part to be cooled.

Regenerator—A device used in a thermodynamic process for capturing and returning to the process heat that would otherwise be lost. Also called "a heat exchanger"

Relative Humidity (abbr rh)—The (dimensionless) ratio of the actual vapor pressure of the air to the saturation vapor pressure.

Relativistic Particles—In general, pertaining to material, as a subatomic particle, moving at speeds which are an appreciable fraction of the speed of light.

Relativity—A principle that postulates the equivalence of the description of the universe, in terms of physical laws, by various observers, or for various frames of reference.

Rendezvous—The event of two or more objects meeting at a preconceived time and place.

A rendezvous would be involved, for example, in servicing or resupplying a space station.

Resonance—1. The phenomenon of amplification of a free wave or oscillation of a system by a forced wave or oscillation of exactly equal period. The forced wave may arise from an impressed force upon the system or from a boundary condition. The growth of the resonant amplitude is characteristically linear in time. 2. Of a system in forced oscillation, the condition which exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system.

Resonance Frequency—A frequency at which resonance exists. Also called "resonant frequency."

In case of possible confusion, the type of resonance must be indicated; as "velocity resonance frequency."

Retrorocket—(From 'retroacting'.) A rocket fitted on or in a spacecraft, satellite, or the like to produce thrust opposed to forward motion.

Revolution—Motion of a celestial body in its orbit; circular motion about an axis usually external to the body.

In some contexts the terms "revolution" and "rotation" are used interchangeably; but with reference to the motions of a celestial body, "revolution" refers to the motion in an orbit or about an axis external to the body, while "rotation" refers to motion about an axis within the body. Thus, the earth revolves about the sun annually and rotates about its axis daily.

Rills—Narrow, sharply-defined features that extend across the surfaces of the lunar MARIA. They may be cracks or wrinkles in the lava beds.

Rocket—1. A projectile, pyrotechnic device, or flying vehicle propelled by a rocket engine. 2. A rocket engine.

Rocket Engine—A reaction engine that contains within itself, or carries along with itself, all the substances necessary for its operation or for the consumption or combustion of its fuel, not requiring intake of any outside substance and hence capable of operation in outer space. Also called **"Rocket Motor."**

Rocket Propellant—Any agent used for consumption or combustion in a rocket and from which the rocket derives its thrust, such as a fuel, oxidizer, additive, catalyst, or any compound or mixture of these. "Rocket propellant" is often shortened to "propellant."

Rocketsonde—Meteorological rocket

Rockoon—A high-altitude sounding system consisting of a small solid-propellant research rocket launched from a large plastic balloon.

The rocket is fired near the maximum altitude of the balloon flight. It is a relatively mobile rocket-sounding system, and has been used extensively from shipboard.

Roentgen—That amount of x or gamma radiation sufficient to produce ions carrying one electrostatic unit of charge in one cm^3 of air. The term is loosely used to signify that amount of any ionizing radiation which produces the same effect as one roentgen of gamma rays. The average person receives about 0.1 roentgen per year of total body radiation from COSMIC RAYS and the radioactivity of the earth. Five hundred roentgens of full body radiation is fatal to most people.

Roll—The rotational or oscillatory movement of an aircraft or similar body which takes place about a longitudinal axis through the body—called "roll" for any amount of such rotation.

Rotation—Turning of a body about an axis within the body, as the daily rotation of the earth. See **Revolution.**

Rumble—A form of combustion instability, especially in a liquid-propellant rocket engine, characterized by a low-pitched, low-frequency rumbling noise; the noise made in this kind of combustion.

S

Satellite—1. An attendant body that revolves about another body, the primary; especially in the solar system, a secondary body, or moon, that revolves about a planet. 2. A man made object that revolves about a spatial body, such as Explorer I orbiting about the earth.

Scale Height—A measure of the relationship between density and temperature at any point in an atmosphere; the thickness of a homogeneous atmosphere which would give the observed temperature or pressure.

Schlieren—(German, "streaks," "striae.") 1. Regions of different density in a fluid, especially as shown by special apparatus. 2. A method or apparatus for visualizing or photographing regions of varying density in a field of flow.

Screaming—A form of combustion instability, especially in a liquid-propellant rocket engine, of relatively high frequency and characterized by a high-pitched noise.

Scrub—To cancel a scheduled rocket firing, either before or during countdown.

Secondary Cosmic Rays—Secondary emission in the atmosphere stimulated by primary cosmic rays.

Seeing—A blanket term long used by astronomers for the disturbing effects produced by the atmosphere upon the image quality of an observed astronomical body.

Selenocentric—Relating to the center of the moon; referring to the moon as a center.

Selenographic—1. Of or pertaining to the physical geography of the moon. 2. Specifically, referring to positions on the moon measured in latitude from the moon's equator and in longitude from a reference meridian.

Semicircular Canals—Tubes located in the inner ear which play a part in the mechanism of balance and orientation.

Sensible Atmosphere—That part of the atmosphere that offers resistance to a body passing through it. See **Effective Atmosphere.**

Sensor—The component of an instrument that converts an input signal into a quantity which is measured by another part of the instrument. Also called "sensing element."

Service Tower—Gantry Scaffold.

Shadowgraph—A picture or image in which steep density gradients in the flow about a body are made visible, the body itself being presented in silhouette.

Shaker—An electromagnetic device capable of imparting known, and/or controlled vibratory acceleration to a given object.

Shield—Short for "radiation shield"; "heat shield."

Shock Tube—A relatively long tube or pipe in which very brief high-speed gas flows are produced by the sudden release of gas at very high pressure into a low-pressure portion of the tube; the high-speed flow moves into the region of low pressure behind a shock wave.

The shock tube is used as a tool in the study of gases or as a kind of intermittent wind tunnel.

Shock Waves—The phenomena in compressible fluid flow where a positive pressure disturbance propagates and eventually steepens into a shock front. In the limit of a perfect fluid conductor, such variables as velocity, pressure density, temperature, and magnetic field can change discontinuously across a shock front. A high-velocity shock can be driven by passing a large electric current through a highly ionized PLASMA. Highly ionized shocks which propagate through a magnetic field are called MAGNETOHYDRODYNAMIC (MHD) shock waves.

Shoran—(From "short range navigation.") A precision electronic position fixing system using a pulse transmitter and receiver and two transponder beacons at fixed points.

Shot—An act or instance of firing a rocket, especially for the earth's surface, as "the shot carried the rocket 200 miles."

Shroud—The nosecone of a space vehicle when it is used only as a shield for passage through the atmosphere from launch to orbit. It is usually jettisoned when orbital speed is achieved.

Sidereal—Of or pertaining to the stars.

Sloshing—The back-and-forth splashing of a liquid fuel in its tank, creating problems of stability and control in the vehicle.

Slug—A unit of mass; the mass of a free body which if acted upon by a force of 1 pound would experience an acceleration of 1 foot per second per second.

Slurry—A suspension of fine solid particles in a liquid.

Soft Radiation—Radiation which is absorbed by an absorber equivalent to 10 centimeters of lead or less. Radiation which can penetrate more than 10 centimeters of lead is termed "hard radiation."

Solar Atmospheric Tide—Vertical motion of the atmosphere due to thermal or gravitational action of the sun.

Solar Cell—A photovoltaic device that converts sunlight directly into electrical energy.

Solar Constant—The rate at which solar radiation is received on a surface perpendicular to the incident radiation and at the earth's mean distance from the sun, but outside the earth's atmosphere.

Solar Cycle—The observed fluctuation from maximum to minimum of the incidence of SUNSPOTS, and the activity of SOLAR FLARES and prominences, with a mean period of 11.2 years. There is also evidence that the overall magnetic field of the sun fluctuates with the same period.

Solar Flare—Sudden local increase in the intensity of the light of hydrogen on the sun. Some solar flares are associated with the expulsion of charged particles and the production of radio bursts.

Solar Plasma—See **Solar Wind.**

Solar Radiation—The total electromagnetic radiation emitted by the sun.

Solar Wind—A stream of protons constantly moving outward from the sun. Synonymous with solar plasma.

Solid Propellant—Specifically, a rocket propellant in solid form, usually containing both fuel and oxidizer combined or mixed and formed into a monolithic (not powdered or granulated) grain. See **Rocket Propellant and Grain.**

Solid-Propellant Rocket Engine—A rocket engine using a solid propellant. Such engines consist essentially of a combustion chamber containing the propellant, and a nozzle for the exahust jet, although they often contain other components, as grids, liners, etc. See **Rocket Engine** and **Solid Propellant.**

Sonic—1. Aerodynamics: Of or pertaining to the speed of sound; that moves at the speed of sound, as in "sonic flow"; designed to operate or perform at the speed of sound, as in "sonic leading edge." 2. Of or pertaining to sound, as in "sonic amplifier".

Sonic Boom—A noise caused by the shock wave that emanates from an aircraft or other object traveling in the atmosphere at or above the speed of sound.

Sonic Speed—The speed of sound; by extension, the speed of a body traveling at Mach 1.

Sound travels at different speeds through different *mediums and at different speeds through any given medium under different conditions of temperature, etc. In the standard atmosphere at sea level, sonic speed is approximately 760 miles per hour.*

Sounding—1. In geophysics, any penetration of the natural enviroment for scientific observation. 2. In meteorology, same as upper-air observation. However, a common connotation is that of a single complete radiosonde observation.

Sounding Rocket—A rocket designed to explore the atmosphere within 4,000 miles of the earth's surface.

Space—1. Specifically, the part of the universe lying outside the limits of the earth's atmosphere. 2. More generally, the volume in which all spatial bodies, including the earth, move.

Space-Air Vehicle—A vehicle that may be operated either within or above the sensible atmosphere.

Spacecraft—Devices, manned or unmanned, which are designed to be placed into an orbit about the earth or into a trajectory to another celestial body.

Space Equivalent—A condition within the earth's atmosphere that is virtually identical, in terms of a particular function, with a condition in outer space.

For example, at 50,000 feet the low air pressure and the scarcity of oxygen create a condition, so far as respiration is concerned, that is equivalent to a condition in outer space where no appreciable oxygen is present; thus, a physiological space equivalent is present in the atmosphere.

Space Medicine—A branch of aerospace medicine concerned specifically with the health of persons who make, or expect to make, flights into space beyond the sensible atmosphere.

Space Probe—See **Probe.**

Space Reddening—The observed reddening, or absorption of shorter wavelengths, of the light from distant celestial bodies caused by scattering by small particles in interstellar space. Compare **red shift.**

Space Simulator—A device which simulates some condition or conditions existing in space and used for testing equipment, or in training programs.

Space System—A system consisting of launch vehicle(s), spacecraft and ground support equipment.

Space Vehicle—A launch vehicle and its associated spacecraft.

Spatial—Pertaining to space.

Spatio—A combining form meaning "space."

Specific Impulse—A performance parameter of a rocket propellant, expressed in seconds, and equal to thrust (in pounds) divided by weight flow rate (in pounds per second). See **Thrust.**

Spectrometer—An instrument which measures some characteristics such as intensity, of electromagnetic radiation as a function of wavelength or frequency.

Spectrum—1. In physics, any series of energies arranged according to wavelength (or frequency); specifically, the series of images produced when a beam of radiant energy, such as sunlight, is dispersed by a prism or a reflecting grating. 2. Short for "electromagnetic spectrum" or for any part of it used for a specific purpose as the 'radio spectrum' (10 kilocycles to 300,000 megacycles).

Sputtering—Dislocation of surface atoms of a material bombarded by high-energy atomic particles.

Stage—A propulsion unit of a rocket, especially one unit of a multistage rocket, including its own fuel and tanks.

Stage-and-a-Half—A liquid-rocket propulsion unit of which only part falls away from the rocket vehicle during flight, as in the case of booster rockets falling away to leave the sustainer engine to consume remaining fuel.

Standard Atmosphere—1. A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables, etc. 2. A standard unit of atmospheric pressure exerted by a 760 mm column of mercury at gravity (980.665 cm/sec^2) at temperature 0°C.

One standard atmosphere = 760 mm Hg
= 29.9213 in. Hg
= 1013.250 mb

Stationary Orbit—An orbit in which an equatorial satellite revolves about the primary at the same angular rate as the primary rotates on its axis. From the primary, the satellite thus appears to be stationary over a point on the primary.

Stefan-Boltzmann Law—One of the radiation laws which states that the amount of energy radiated per unit time from a unit surface area of an ideal black body is proportional to the fourth power of the absolute temperature of the black body.

Stoichiometric—Of a combustible mixture, have the exact proportions required for complete combustion.

Stratosphere—The region of the atmosphere lying on the average between about 12 and 60 kilometers; it has a temperature which is either constant or increases with altitude, and is therefore stable against convection. The upper part of the stratosphere is at a temperature of about 260°K, and is heated by the absorption of ultraviolet light by OZONE.

Subassembly—An assembly within a larger assembly.

Subatomic Particle—A component of an atom, such as an electron, a proton, a meson, etc.

Subsonic—In aerodynamics, dealing with speeds less than the speed of sound (see sonic speed), as in "subsonic aerodynamics."

Subsystem—A functioning entity within a major system (launch vehicle, spacecraft, etc.) of a space system such as propulsion subsystem of a launch vehicle or attitude control subsystem of a spacecraft. Also considered a system.

Sudden Ionospheric Disturbance—(Often abbreviated SID). A complex combination of sudden changes in the condition of the ionosphere, and the effects of these changes.

Sunspot—A relatively dark area on the surface of the sun, consisting of a dark central umbra surrounded by a penumbra which is intermediate in brightness between the umbra and the surrounding photosphere.

Sunspots usually occur in pairs with opposite magnetic polarities. They have a lifetime ranging from a few days to several months. Their occurrence exhibits approximately an eleven year period (the sunspot cycle).

Sunspot Cycle—A cycle with an average length of 11.1 years, but varying between about 7 and 17 years, in the number and area of sunspots, as given by the relative sunspot number. This number rises from a minimum of 0-10 to a maximum of 50-140 about four years later, and then declines more slowly.

An approximate 11-year cycle has been found or suggested in geomagnetism, frequency of aurora, and other ionospheric characteristics.

Eleven-year cycles have been suggested for various tropospheric phenomena, but none of these has been substantiated.

Supersonic—Pertaining to speeds greater than the speed of sound. Compare **ultrasonic.**

Surveyor—The United States program for the scientific exploration of the surface and subsurface of the moon, following the RANGER program. Surveyor A, designed to make SOFT LANDINGS on the moon, will explore the physical, chemical, and mineralogical properties of the moon at the landing site. It is expected to be launched using an ATLAS-Centaur in the last half of 1964. Surveyor B will be placed in a stable orbit about 60 miles above the lunar surface. It will allow a scan by television of the visible and hidden faces of the moon, and will be used for a preliminary selection of APOLLO landing sites, as well as permit studies of radiation near the lunar surface, and the gravity and mass distribution of the moon. The launching of a total of seven Surveyor A's and 5 Surveyor B's is currently planned.

Sustainer Engine—An engine that maintains the velocity of a missile rocket vehicle once it has achieved its programmed velocity by use of booster or other engine.

This term is applied, for example, to the remaining engine of the Atlas after the two booster engines have been jettisoned. The term is also applied to a rocket engine used on an orbital glider to provide the small amount of thrust now and then required to compensate for the drag imparted by air particles in the upper atmosphere.

Sweep—The motion of the visible dot across the face of a cathode-ray tube, as a result of scanning deflection of the electron beam.

Synchronous Rotation—Rotation of a planet or satellite about its axis with the same period as its revolution about a parent body, with the axis of rotation assumed perpendicular to the plane of the orbit. A consequence of this type of rotation is that the planet or satellite always presents the same side or face to the parent body. The moon rotates synchronously with respect to the earth, and Mercury with respect to the sun. There is some evidence that Venus also rotates synchronously with respect to the sun, or at least has a day comparable in length to its year. Synchronous rotation is usually assumed to be caused by TIDAL DRAG acting during the planet's past.

Synchrotron Radiation—Electromagnetic radiation generated by the acceleration of charged relativistic particles (usually electrons) in a magnetic field. Radiation of this kind was first encountered in the particle accelerator called the synchrotron. It is an important mechanism for the generation of nonthermal, continuous radio waves in supernova fragments and galactic halos.

Synchronous Satellite—An equatorial west-to-east satellite orbiting the earth at an altitude of 22,300 statute miles at which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation.

Synergic Curve—A curve plotted for the ascent of a rocket, space-air vehicle, or space vehicle calculated to give the vehicle an optimum economy in fuel with an optimum velocity.

This curve, plotted to minimize air resistance, starts off vertically, but bends towards the horizontal between 20 and 60 miles altitude.

System—1. An organized arrangement in which the operational results of two or more functioning entities can be predicted.

2. Used in term, space system, to mean the launch vehicle, spacecraft and ground support used in a space launch and flight.

3. One of major subdivisions of a space system, such as launch vehicle, spacecraft, or ground support system.

4. One of major functioning entities within a major subdivision of a space system, such as the guidance system of a launch vehicle or the attitude control system of a spacecraft.

In sense 4, synonymous with subsystem.

Systems Intergration—The management process by which the systems of a project (for example, the launch vehicle, the spacecraft, and its supporting ground equipment and operational procedures) are made compatible, in order to achieve the purpose of the project or the given flight mission.

T

Tektite—A small glassy body containing no crystals, probably of meteoritic origin, and bearing no antecedent relation to the geological formation in which it occurs.

Tektites are found in certain large areas called "strewn fields." They are named as minerals with the suffix "ite," as "australite," found in Australia; "billitonite," "indochinite," and "rizalite," found in Southeast Asia; "bediasite" from Texas, and "moldavite" from Bohemia and Moravia.

Telemetry—The science of measuring a quantity or quantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured.

Terminator—The line separating illuminated and dark portions of a nonluminous body, as the moon.

Terrestrial—Pertaining to the earth.

Thermal Radiation—The electromagnetic radiation emitted by a hot blackbody, such as the filament of a lamp. The distribution of energy with frequency of thermal radiation is given by PLANCK'S LAW. The sun radiates approximately as a blackbody with a temperature of about 5700°K. (See NONTHERMAL RADIATION.)

Thermocouple—A temperature-sensing element which converts thermal energy directly into electrical energy. In its basic form it consists of two dissimilar metallic electrical conductors connected in a closed loop. Each junction forms a thermocouple.

If one thermocouple is maintained at a temperature different from that of the other, an electrical current proportional to this temperature difference will flow in the circuit; the value of this proportionality varies with materials used. For meteorological purposes, couples of copper and constantan are frequently used which generate approximately 40 microvolts per °C of couple temperature difference.

Thermodynamic—Pertaining to the flow of heat or to thermodynamics.

Thermodynamics—The study of the relationships between heat and mechanical energy.

Thermonuclear—Pertaining to a nuclear reaction that is triggered by particles of high thermal energy.

Thermosphere—The region of the atmosphere, above the MESOSPHERE, in which there is strong heating and increasing temperature, resulting from the PHOTODISSOCIATION of O_2 and the PHOTOIONIZATION of N, N_2 and O. It extends roughly from an altitude of 90 to 600 kilometers.

Thrust—1. The pushing force developed by an aircraft engine or a rocket engine. 2. Specifically, in rocketry, the product of propellant mass flow rate and exhaust velocity relative to the vehicle.

Thrust-to-Weight Ratio—The ratio of the engine THRUST of a rocket to the total vehicle weight. This ratio must be greater than one to lift the vehicle off the ground.

Tidal Drag—The damping of a planet or satellite's rotation produced by frictional losses associated with tides raised either in the solid body of the planet or satellite, or in seas upon its surface. (See SYNCHRONOUS ROTATION.)

Tiros—A series of United States meteorological satellites designed to observe the cloud coverage of the earth and measure the heat radiation emitted by the earth in the infrared.

Topside Sounder—A satellite designed to measure ion concentration in the ionosphere from above the ionosphere.

Tore or Torus—In geometry the surface described by a conic section, especially a circle, rotating about a straight line in its own plane or the solid of revolution enclosed by such a surface. Hence, the extended sections of a manned space laboratory, having a generally circular configuration and rotating around a stationary central section.

Torr. (From Torricelli)—Suggested international standard term to replace the English term "millimeter of mercury" and its abbreviation "mm of Hg" (or the French "mm de Hg").

Both "Tor" and "Torr" have been used in Germany, the latter spelling being more common and the one officially adopted by the German Standards Association. The "Torr" is defined as 1/760 of a standard atmosphere or 1,013,250/760 dynes per square centimeter. This is equivalent to defining the "Torr" as 1333.22 microbars and differs by only one part in seven million from the International Standard millimeter of mercury. It is recommended that "Torr" not be abbreviated. However, the abbreviation τ has been used. The prefixes "milli" and "micro" are attached without hyphenation.

Tracking—The process of following the movement of a satellite or rocket by radar, radio, and photographic observations.

Trajectory—In general, the path traced by any body, as a rocket, moving as a result of externally applied forces.

Trajectory is loosely used to mean "flight path" or "orbit."

Transducer—A device capable of being actuated by energy from one or more transmission systems or media, as a microphone, a thermocouple, etc.

Transfer Orbit—In interplanetary travel an elliptical trajectory tangent to the orbits of both the departure planet and the target planet.

Transit—1. The passage of a celestial body across a celestial meridian; usually called "meridian transit." 2. The apparent passage of a celestial body across the face of another celestial body or across any point, area, or line.

Translunar—Of or pertaining to space outside the moon's orbit about the earth.

Transponder—A combined receiver and transmitter whose function is to transmit signals automatically when triggered by an interrogating signal.

Transponder Beacon—A beacon having a transponder.

T-Time—Any specific time, minus or plus, as referenced to "zero," or "launch" time, during a countdown sequence that is intended to result in the firing of a rocket propulsion unit that launches a rocket vehicle or missile.

Troposphere—That portion of the atmosphere from the earth's surface to the tropopause; that is, the lowest 10 to 20 km of the atmosphere. The troposphere is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water vapor content, and weather. Dynamically, the troposphere can be divided into the following layers: surface boundary layer, Ekman layer, and free atmosphere.

U

Ullage—The amount that a container, such as a fuel tank, lacks of being full.

Ultrasonic—Of or pertaining to frequencies above those that affect the human ear, i.e., more than 20,000 vibrations per second.

The term "ultrasonic" may be used as a modifier to indicate a device or system intended to operate at an ultrasonic frequency.

Although "supersonic" was formerly used in acoustics synonymously with "ultrasonic," this usage is now rare.

Ultraviolet Radiation—Electromagnetic radiation shorter in wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4000 angstroms.

Ultraviolet radiation from the sun is responsible for many complex photochemical reactions characteristic of the upper atmosphere, e.g., the formation of the ozone layer through ultraviolet dissociation of oxygen molecules followed by recombination to form ozone.

Umbilical Cord—Any of the servicing electrical or fluid lines between the ground or a tower and an upright rocket missile or vehicle before the launch. Often shortened to 'umbilical'.

Upper-Air Observation—A measurement of atmospheric conditions aloft, above the effective range of a surface weather observation. Also called "sounding," "upper-air sounding."

V

Van Allen Belt, Van Allen Radiation Belt—[For James A. Van Allen, 1915-.] The zone of high-intensity radiation surrounding the earth beginning at altitudes of approximately 1000 kilometers.

The radiation of the Van Allen belt is composed of protons and electrons temporarily trapped in the earth's magnetic field. The intensity of radiation varies with the distance from the earth, thus the Van Allen belt is often considered as two belts or zones, with maxima of intensity at approximately 3600 kilometers and 16,000 kilometers.

Vehicle—Specifically, a structure, machine, or device, such as an aircraft or rocket, designed to carry a burden through air or space; more restrictively, a rocket craft.

This word has acquired its specific meaning owing to the need for a term to embrace all flying craft, including aircraft and rockets.

Vehicle Control System—A system, incorporating control surfaces or other devices, which adjusts and maintains the altitude and heading, and sometimes speed, of the vehicle in accordance with signals received from a guidance system.

The essential difference between a control system and a guidance system is that the control system points the vehicle and the guidance system gives the commands which tell the control system where to point. However, the control system maintains the instantaneous orientation of the vehicle without specific commands from the guidance system.

Vernier Engine—A rocket engine of small thrust used primarily to obtain a fine adjustment in the velocity and trajectory of a ballistic missile or space vehicle just after the thrust cutoff of the last propulsion engine, and used secondarily to add thrust to a booster or sustainer engine. Also called 'vernier rocket'.

Vertical—The direction in which the force of gravity acts.

Visible Radiation—Electromagnetic radiation lying within the wavelength interval to which the human eye is sensitive, which is from approximately 0.4 to 0.7 micron (4000 to 7000 angstroms). This portion of the electromagnetic spectrum is bounded on the shortwavelength end by ultraviolet radiation, and on the longwavelength end by infrared radiation.

Voyager—A series of spacecraft which will be launched by the United States as a successor to the MARINER program. Voyager craft, launched using the Saturn, will be directed into stable orbits around Mars and Venus, and will attempt to SOFT-LAND instrumented payloads on both these planets. Others may be used for flyby studies of Mercury and Jupiter.

W

Waveguide—A system of material boundaries capable of guiding electromagnetic waves.

Weight--The force with which an earth-bound body is attracted toward the earth.

Weightlessness—A condition in which no acceleration, whether of gravity or other force, can be detected by an observer within the system in question.

Any object falling freely in a vacuum is weightless, thus an unaccelerated satellite orbiting the earth is "weightless" although gravity affects its orbit. Weightlessness can be produced within the atmosphere in aircraft flying a parabolic flight path.

Waiver—Granted use or acceptance of an article which does not meet specified requirements.

Whistler—A radio-frequency electromagnetic signal sometimes generated by lightning discharges.

This signal apparently propagates along a geomagnetic line of force, and often "bounces" several times between the Northern and Southern Hemispheres. Its name derives from the sound heard on radio receivers.

X

X-Ray—Electromagnetic radiation of very short wavelength, lying within the wavelength interval of 0.1 to 100 angstroms (between gamma rays and ultraviolet radiation', 'Roentgen ray).

X-rays penetrate various thickness of all solids and they act upon photographic plates in the same manner as light. Secondary X-rays are produced whenever X-rays are absorbed by a substance, in the case of absorption by a gas, this results in ionization.

Y

Yaw—1. The lateral rotational or oscillatory movement of an aircraft, rocket, or the like about a transverse axis. 2. The amount of this movement, i.e., the angle of yaw.

Year of the Quiet Sun—Eleven year low period in solar activity which is expected between April, 1964 and December, 1965. The international program for maximum observation and research in this interval is termed International Year of the Quiet Sun (IQSY).

Z

Zenith—That point of the celestial sphere vertically overhead. The point 180° from the zenith is called the "nadir."

Zero G = Weightlessness.